AEDC-TR-73-120
(Supersedes TOD 71-43)

cy.10

AEDC
FISCAL YEAR 1974
AIR FORCE TECHNICAL OBJECTIVE DOCUMENT

September 1973

Approved for public release; distribution unlimited.

DIRECTORATE OF TECHNOLOGY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

THIS DOCUMENT IS FOR INFORMATION AND GUIDANCE ONLY

This document is furnished for information and general guidance only; it is not to be construed as a request for proposal, or as a commitment by the government to issue a contract, or as authority to incur expenses in anticipation of a government contract; nor is it to be used as the basis of a claim against the government. The furnishing of this document by the government is not to be construed to obligate your company to furnish to the United States Government any experimental, developmental, research, or production articles, services, or proposals, or comment with respect to such document, the TOD program or any aspects of either.

AEDC-TR-73-120
(Supersedes TOD 71-43)

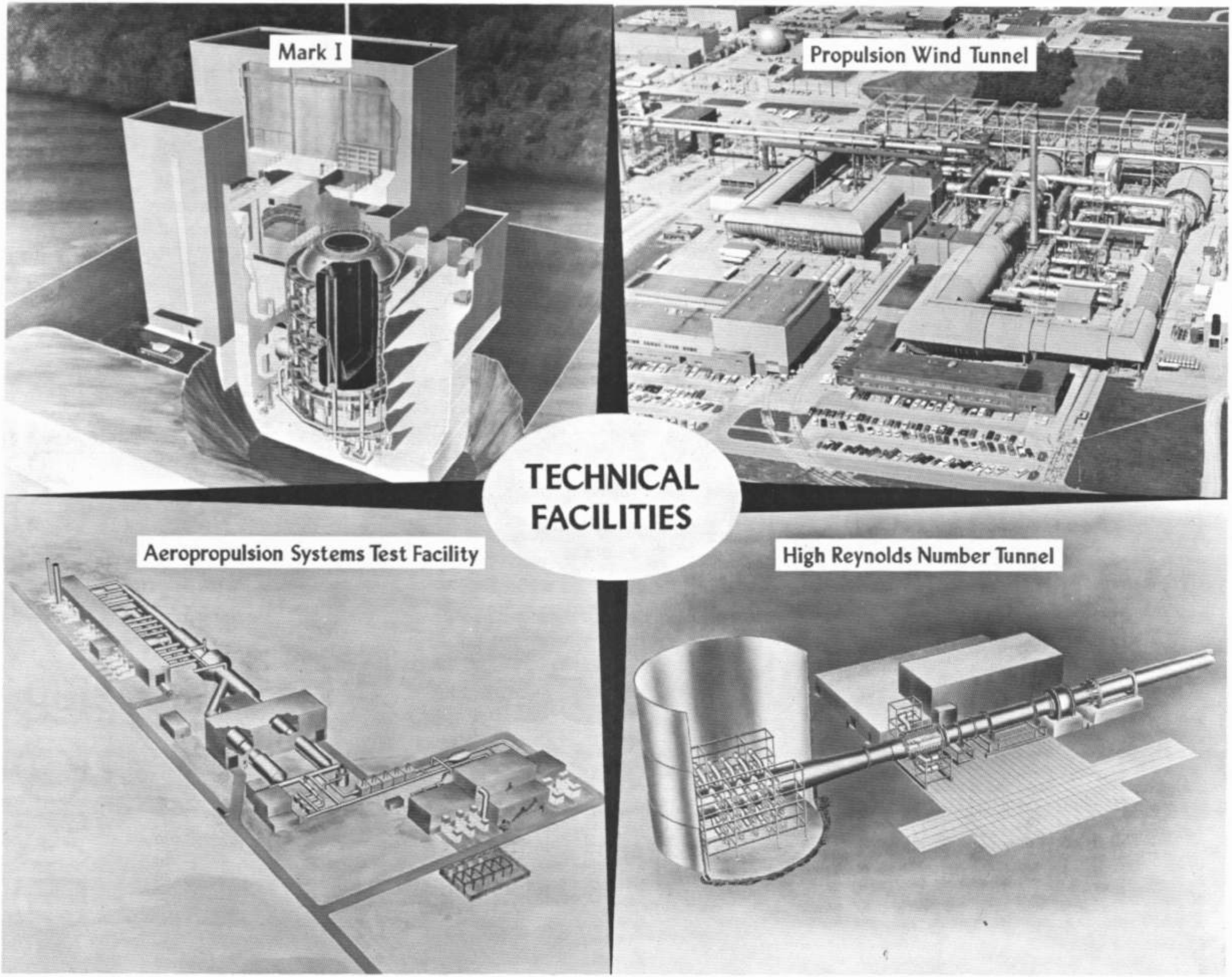
ARNOLD ENGINEERING DEVELOPMENT CENTER
Arnold Air Force Station, Tennessee

AEDC
FISCAL YEAR 1974
AIR FORCE TECHNICAL OBJECTIVE DOCUMENT

Approved for public release; distribution unlimited.

AIR FORCE SYSTEMS COMMAND
United States Air Force

TECHNICAL FACILITIES



FOREWORD

It is mandatory that we continue to advance technology vigorously or risk losing our technological leadership. This leadership is essential to our national security and enables the United States Air Force, in support of national policy, to maintain a distinct military advantage in aerospace power.

Attainment of our research and development goals requires the coordinated efforts of the nation's technological resources. Teamwork on the part of the Air Force laboratories and the industrial and academic research and development community in accomplishing selected technical objectives provides the foundation for the future defense of the United States.

The Air Force Technical Objective Document Program is a key factor in this endeavor. This program describes technical planning objectives to be attained for the future operational needs of the Air Force. The Technical Objective Documents (TODs) should not confine, but stimulate, your thinking. The primary purposes of our TODs are to:

--Provide planning information for independent research and development programs.

--Improve the quality of the unsolicited proposals and R & D procurements, and

--Encourage face-to-face discussions between nongovernment scientists and engineers and their Air Force counterparts.

TODs are prepared and published by the Air Force laboratories; classified TODs are available from the Defense Documentation Center (DDC) and unclassified TODs are available from the National Technical Information Service (NTIS).

On behalf of the United States Air Force, you are invited to study the technical planning objectives listed in this document and to discuss them with the responsible Air Force laboratory. Your ideas and proposals, whether in response to the TODs or not, are most welcome.

ABSTRACT

This report describes eighteen technical objectives in environmental facility simulation.technology. The facility technology of concern includes new facility technology improvements in test techniques, instrumentation technology, gas properties and comparison of wind tunnel and flight test data. These technical objectives constitute the Arnold Engineering Development Center's FY 1974 Technical Objectives Document. This document supersedes TOD 71-43.

CONTENTS

1.0 INTRODUCTION

THE AIR FORCE TECHNICAL PROGRAM

The Air Force Technical Program is dedicated to the generation of the techniques and attendant demonstration of feasibility that will provide the United States Air Force with increased operational capabilities superior to those of any potential enemy.

THE PURPOSE OF THE DOCUMENT

One or more Technical Objective Documents (TOD) have been prepared by each Air Force Laboratory that has responsibility for a portion of the Air Force Technical Program. TOD's provide the academic and industrial R &D community with specific technical planning objectives, the attainment of which the Air Force feels is critical to maintaining aerospace superiority in the years ahead. As you read through the pages that follow, you may see a field of endeavor where your organization can contribute to the achievement of a specific technical goal. If such is the case, you are invited to discuss the objective further with the scientist or engineer identified with that objective. Further, you may have completely new ideas not considered in this document which, if brought to the attention of the proper organization, can make a significant contribution to our military technology. We will always maintain an open mind in evaluating any new concepts which, when successfully pursued, would add to our store of knowledge and advance the state-of-the-art.

TECHNOLOGY PLANNING METHODOLOGY

The Air Force scope of interest in science and technology is very broad, but by no means all-inclusive. The technical planning objectives state what must be done in those areas of technology which are expected to contribute to increased future operational capabilities. It is therefore appropriate to describe the planning methodology used to derive the objectives.

The planning methodology is based upon the concept of establishing goals and subsequently identifying the technology to satisfy these goals. This is a gross oversimplification of the process and required further exploration to fully appreciate the complexity, depth, and value of the

methodology. Before discussing each of the elements of the process in detail, it should be noted that although the methodology is basically goal oriented, it does recognize and allow for the exploitation of technological opportunities.

The accompanying chart, Figure 1, shows the elements of the technology planning methodology. The process starts with defining the capabilities that are required to satisfy the National Security Objectives. This is influenced by National policy, the threat, and the environment. The desired capability is that capability necessary to accomplish a mission or sub-mission assigned to the Air Force. It is the "job to be done" without regard to the systems which can do the job and, as such, is influenced by the long range objective of the Air Force. These desired capabilities also serve as a source of information in the formulation of research planning guidance.

Technology forecasts enable Hq USAF, the development planners at Hq AFSC and the product divisions, and the laboratory planners to postulate, through a capability analysis, numerous competitive methods for accomplishing the long range Air Force objectives. These "ways to do the job" are called System Concept Possibilities.

The same organizations must apply judicious selectivity to this listing of system concept possibilities to arrive at a list of most probable systems. Mission analyses are employed to assist in the selection process and further amplified to identify technology gaps in the resulting most probable systems. The laboratories play a major role in identifying the technological deficiencies which are grouped into similar areas of technology containing common objectives. These common objectives constitute the laboratories' technology planning objectives (TPOs). The laboratory internally develops a technical plan consisting of specific efforts to satisfy the TPOs. The Arnold Engineering Development Center (AEDC) internally develops technical objectives (TOs) for its technology planning as opposed to the laboratories TPOs. The AEDC technology program consists of specific efforts to satisfy the TOs. These plans provide for responsive technology as well as technology for which a quantitative payoff cannot be calculated but appears to be very promising. This represents a source of technology opportunities.

The AEDC is responsible to its customers for defining deficiencies identified in existing systems and technical problems associated with systems currently in development by applying new technology toward new and/or better environmental testing for systems. Research needs identified within the TOs are used as another source of guidance for research planning.

At this point, the process provides an unconstrained technology plan based on the best guidance available with regard to needs. From the technology plan, a current year program is prepared through application of priorities and resource limitations. After the program is implemented, exploitation of the technology provides additional technological opportunities.

These same technology plans are used as the basis for the AEDC TOD.

HOW TO USE THIS DOCUMENT

Unsolicited proposals to conduct programs leading to the attainment of any of the objectives presented in this document may be submitted directly to the Air Force laboratory. However, before submitting a formal proposal, we encourage you to discuss your approach with the laboratory point of contact, whose name, address, and telephone number appear at the end of the technical objective. After your discussion or correspondence with the laboratory personnel, you will be better prepared to write your proposal.

As stated in the "AFSC Guide for Unsolicited Proposals" (copies of this informative guide on unsolicited proposals are available by writing to Air Force Systems Command/PPPR, Andrews Air Force Base, Washington, DC 20331), elaborate brochures or presentations are definitely not desired. The ABC's of successful proposals are accuracy, brevity, and clarity. It is extremely important that your letter be prepared to encourage its reading, to facilitate its understanding, and to impart an appreciation of the ideas you desire to convey. Specifically, your letter should include the following:

1. Name and address of your organization.
2. Type of Organization (Profit, Nonprofit).
3. Concise title and abstract of the proposed research and the statement indicating that the submission is an unsolicited proposal.
4. An outline and discussion of the purpose of the research, the method of attack upon the problem, and the nature of the expected results.
5. Name and research experience of the principal investigator.
6. A suggestion as to the proposed starting and completion dates.

7. An outline of the proposed budget, including information on equipment, facility, and personnel requirements.
8. Names of any other Federal agencies receiving the proposal. (This is extremely important.)
9. Brief description of your facilities, particularly those which would be used in your proposed research effort.
10. Brief outline of your previous work and experience in the field.
11. If available, you should include a descriptive brochure and a financial statement.

CONSTRUCTIVE SUGGESTIONS ARE ENCOURAGED

Critiques or suggestions for improving the Technical Objective Documents are encouraged; they should be directed to:

Air Force Systems Command/DLXL
Andrews Air Force Base
Washington, DC 20334

2.0 MANAGEMENT OVERVIEW

CENTER MISSION

AEDC supports the timely acquisition of superior aerospace systems by conducting research, development, test, analysis and evaluation, and studies utilizing, as appropriate, aerospace environmental testing facilities for the Air Force, other Government agencies, and industry.

COMMANDER'S ASSESSMENT OF THE MISSION

The Arnold Engineering Development Center is the free world's largest complex of ground environmental test facilities equipped and devoted to determining the performance of aircraft and space systems equipment before it is committed to flight. Timely and adequately planned use of AEDC facilities can insure that many problems encountered in the development of aerospace hardware are explored and solved well before critical program decision points. Identical tests of

two or more items can be performed when comparative evaluation of component, subsystems, or system performance is necessary or desired. The primary thrust of AEDC effort is to insure that information provided to program and project managers, either as test data or evaluation of results, is of the highest quality, credible and adequate to support development decisions. By doing so, AEDC helps to insure that only systems with a high probability of mission success enter the flight test phase of acquisition.

The AEDC has been recognized as a technological leader since its inception. As more complex aerospace systems are conceived and developed, the performance demands on various components are increased and greater precision and care must be taken in their development. As a consequence, AEDC's role in supporting system development is more demanding in planning test programs, in providing its customers with test data, and in analyzing and evaluating the data. Within the Air Force Systems Command, AEDC works in close collaboration with the Aeronautical Systems Division, the Space and Missile Space Organization, the Flight Dynamics Laboratory, AeroPropulsion Laboratory and other divisions, centers, and laboratories. The Center also provides test support to other Department of Defense organizations and to the National Aeronautics and Space Administration.

AEDC will assist program and project managers in planning for ground environmental testing, and will conduct such tests of aerospace systems, subsystems, and components as are agreed to be necessary. The Center will perform such engineering analyses and evaluations as are requested by the program managers or are deemed by the Center to be essential to the understanding of test results. AEDC will plan for and implement acquisition of new facilities and improvement of existing facilities and instrumentation to insure adequate test support for future development and acquisition programs. The Center will conduct research and exploratory development to add to the understanding of the physical phenomena involved in the aerospace environment and will use this understanding to improve ground environmental test facilities, instrumentation, and test techniques. To the extent possible within resources available, AEDC will conduct research, analysis, and evaluation of promising areas in the design of aerospace vehicles and their propulsion systems requested by its customers.

AEDC is the Air Force center of excellence for ground environmental testing and will serve as the Air Force Systems Command focal point for matters pertaining to the operation of large aerospace ground environmental test facilities.

MANAGEMENT AND ORGANIZATION

The Arnold Engineering Development Center is a United States Air Force installation.

The Commander, AEDC, is responsible for the accomplishment of the mission. The headquarters has both military and civil service personnel who are responsible for overall planning, direction, scheduling, priorities, and funding associated with accomplishment of the AEDC mission. Management, operation, and maintenance of test facilities and related utilities is accomplished by contract. The Operating Contractor, ARO, Inc., has principal expertise in environmental testing and all technical disciplines relating thereto. ARO, Inc., is in no way involved in the development, production, or sale of aerospace hardware.

The Air Force staff at AEDC assists in the development of and approves the objective, scope, schedule, and relative priority of all environmental test and technology work to be accomplished at AEDC. The accomplishment of tests is the joint responsibility of the test sponsor, ARO, Inc., and the AEDC headquarters staff. New facility planning is the responsibility of the AEDC headquarters with some assistance from the operating contractor. The AEDC technology program planning is the responsibility of the Air Force staff, i.e., the Director of Technology. The technology program consists of conducting research to develop new required test capability (facility technology) and to conduct research for other Air Force, DOD, and government organizations as required. The facility technology work is accomplished by the AEDC contractor and university and industrial contractors.

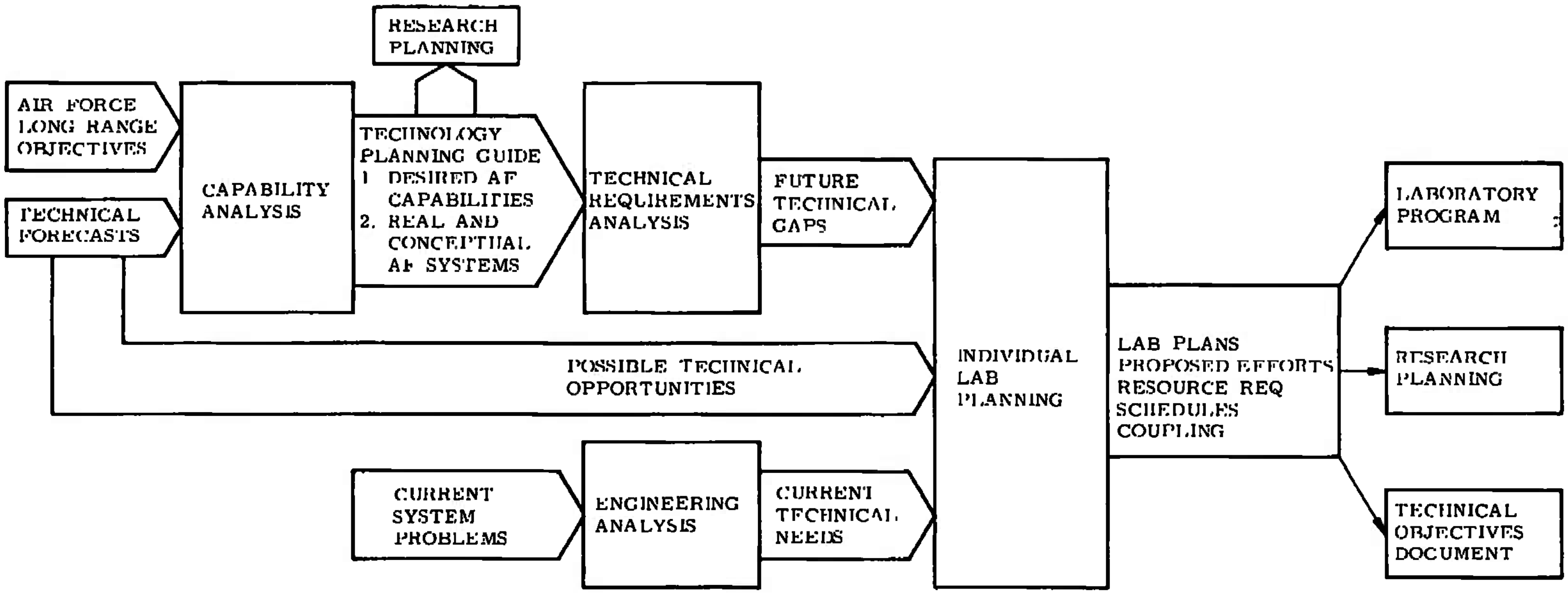
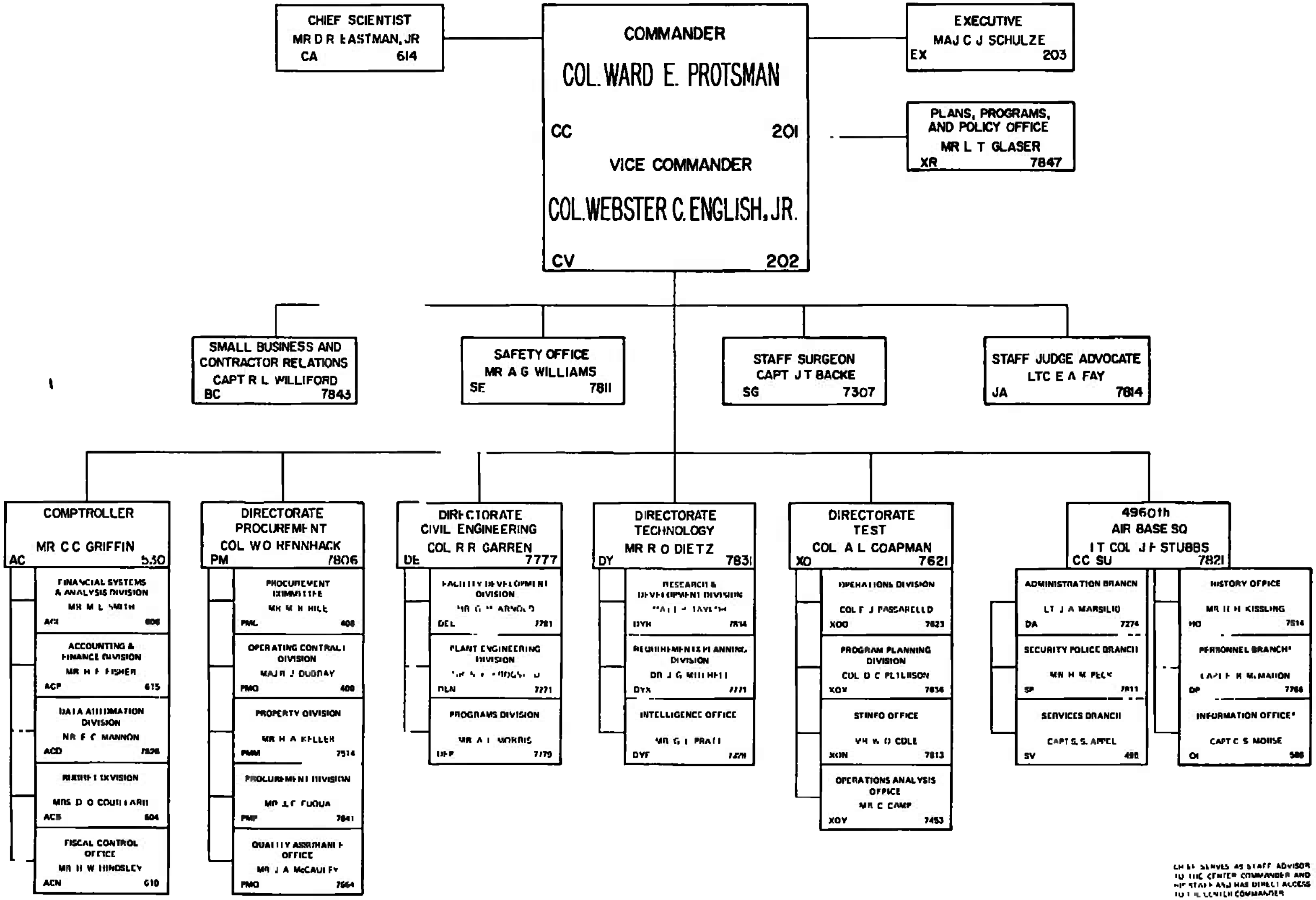


Figure 1 Technology Planning

ARNOLD ENGINEERING DEVELOPMENT CENTER

1 JUNE 1973



3.0 TECHNICAL OBJECTIVES

TO NO. 1: HEATERS FOR FACILITY APPLICATION

OBJECTIVE

1. General. The goal of developing heaters for ablation and ablation/erosion ground test facilities is to simulate the enthalpy and the pressure that the reentry vehicle experiences. The true simulation using a high Mach number air flow is most difficult, since test times of up to two minutes are desirable. The heating of the RV ablation materials is partially simulated, for long time periods, by testing the RV model in a high enthalpy (6,000 - 9,000 Btu/lb_m), high pressure (150 - 200 atmospheres) flow of air. Typical enthalpy profiles of arc heaters currently in use are very peaked. A flatter, more uniform enthalpy profile is required. Another general objective is to develop methods for producing high mass flow at high enthalpies such as is required for testing hypersonic propulsion systems.

2. Specific. The following model stagnation conditions are of interest to reentry testing

Enthalpy (Btu/lb_m)	Pressure (atmosphere)
6000	100-200
7000	100-175
9000	100-150

Hypersonic propulsion testing requires stagnation enthalpy and pressures up to 5000 Btu/lb and 200 atmospheres, respectively.

TECHNICAL APPROACH

1. Segmented Arc Heaters. Using a 5-megawatt (mw) segmented arc heater (constricted or fixed length arc) device, centerline enthalpies up to 5500 Btu/lb_m at 80 atmospheres heater pressure have been produced and measured at AEDC. This exceeds the performance of the best spin stabilized DC arc heaters by 50 percent in enthalpy for this pressure. The segmented arc heater has been operated at 104 atmospheres, but for very short periods. The maximum limits of the current heater design need to be assessed and then a simplified, more mechanically rugged, higher power heater needs to be designed, fabricated and operated to develop heater scaling parameters.

2. "Mini-Max" Arc Heater. This new concept uses a vortex stabilized arc in an axial magnetic field. High heater efficiency is expected by creating a generally uniform temperature profile which in turn minimizes the radiation losses. A 7-mw device is to be tested at AEDC which is expected to achieve 6000 Btu/lb_m enthalpy at 100 atmospheres chamber pressure. The evaluation of this device may indicate the necessity of further evaluation at higher powers so it can be compared to other high enthalpy, high pressure arc heaters for ablation and ablation/erosion test facilities.

3. Electrical Induction Heating of Gases. Electrical induction heating shows promise of producing the desired enthalpy at high pressures. It has no electrodes, thus electrode contamination of the flow is not a problem as with the DC arc heater. Experimental data is currently limited to relatively low heater pressures (50 atm in Argon), low power (100 kw) and low mass flows. Also relatively few experiments have been accomplished with air. Theory and analysis have been developed in recent years to calculate the heater performance, but electrical and radiative gas property data is needed to establish the heater potential with confidence based on theory. Thus far no principle barrier is known which would prevent the development of this heater to the power, pressure, and enthalpy levels required.

Methods of stabilizing the discharge and analytical modeling of the discharge have been accomplished. The absence of solid or liquid particles, characteristic for the electrodeless discharge, contributes an important advantage in comparison with DC arc heaters. As a consequence, application of induction heated flows for the development and calibration of new flow diagnostic techniques is anticipated. A 4-mw power supply and a discharge chamber are currently being built at AEDC. Sufficient experimental work is planned to either confirm or disprove this concept for gas heating at high pressures.

4. Carbon Vitiation Heating. Both analytical and experimental efforts are required to study the feasibility of carbon vitiation heating for producing high temperature large mass flows for hypersonic propulsion testing. This concept potentially can supplement the mass flow which can be achieved with existing zirconia and alumina storage heaters. The production of high temperature air flows by the heating of carbon to create carbon monoxide in an arc heater should be attempted. Using carbon vitiation heating, usable gas flows at temperatures approaching 7000°R appear possible. Assessing carbon fuels in terms of chemical kinetics, combustion chemistry, model wall/gas reactions, and temperature range shows it to be more advantageous than hydrocarbon fuels, primarily because of the absence of water vapor.

REFERENCES

1. Lewis, H. F., et al, "Results of Testing Ultrahigh Pressure Electric Arc Heaters", AEDC-TR-70-228 (AD875816), Oct 1970.

2. Cann, G. L., "An Experimental Investigation of a Vortex Stabilized Arc in an Axial Magnetic Field", ARL-TR-73-0043, 1973.

3. Keefer, D. R., "An Experimental Study of Electrodeless Arc Discharges", AEDC-TR-71-180 (AD729782), Sep 1970.

4. Hollister, D. D., "An Investigation of the High Pressure Electrodeless Arc in Air", AFFDL-TR-68-160.

5. Novack, Martin E., et al, "Research Study to Determine the Optimum Vitiated Heater Configuration and Fuel System for Mach 7-9 True Temperature Simulation", AEDC-TR-68-228 (AD840332), Sep 1968.

6. Edelman, Raymond B., et al, "Analytical Investigation of the Effects of Vitiated Air Contamination on Combustion and Hypersonic Air Breathing Engine Ground Tests", AEDC-TR-69-148 (AD696105), Oct 1969.

7. Davis, R. E., "An Experimental Investigation of the Supersonic Combustion of Vitiated Air - Hydrogen Mixtures", AEDC-TR-70-60, (AD705129), May 1970.

TO FOCAL POINT

Maj Ules L. Barnwell
DYR, Telephone 455-2611 (Ext 7834)

TO NO. 2: ANALYSIS AND EXPERIMENTS IN HIGH ENTHALPY AERODYNAMICS (REAL GAS FLOWS)

OBJECTIVE

1. General. To experimentally establish the existence and magnitude of real gas effects on lifting bodies and reentry vehicles of interest to the Air Force. To compare experimental results obtained under ideal and real gas conditions with each other and with analytical prediction procedures.

2. Specific. Experimental studies on various vehicle geometries will be conducted in the AEDC Tunnel J and corresponding analytical studies will be made using existing or modified computer programs to establish their capability in predicting those vehicle properties mostly affected by the real gas environment. The following basic efforts are required:

a. Calibration of Tunnel J test sections for the test conditions will be required. This includes the determination of the state and composition of the gas in addition to the conventional dynamic properties of the test section flow. Available diagnostic techniques will be employed.

b. Measurement of those model properties will be made which are expected to be most strongly affected by a real gas environment. Such measurements are as follows:

(1) Base and afterbody pressures on sharp and blunt bodies under both ideal and real gas conditions with fully developed turbulent boundary layers, at various angles of attack.

(2) Heating rates on the lower and upper surfaces of lifting bodies and reentry vehicles at various angles of attack.

(3) Pressure distribution and heating rate on control flaps.

(4) Center of pressure.

(5) The measurements outlined under b.(1) to (4) cover only data on surface properties. The reason is that no force balance for Tunnel J exists at present. It is however anticipated that such a force balance providing information on forces and moments (stability) will be required, once the significance of the real gas effects and the usefulness of Tunnel J for user testing under these conditions has been established.

TECHNICAL APPROACH

1. PRESENT STATUS

Real gas effects on hypersonic vehicles have been of concern to the designer for many years. The magnitude of these effects in the past have been estimated mainly by analysis. From the analytical studies of which Ref. 2 is a typical example it has been concluded that in general, simple shapes such as sharp cones at zero angle of attack are not greatly affected by real gas effects but that for even small angles of attack or for more complicated shapes the effects can be important. The magnitude of the effects are predicted to be large enough that for efficient vehicle design they have to be taken into account.

Experimentation to determine the existence and significance of the departure from ideal gas conditions has been very limited in scope, velocity and altitude ranges because of the lack of a ground test facility capability. Flight tests have not provided the required information because of difficulties in data acquisition.

The AEDC under contract with the Cornell Aeronautical Laboratory, Ref. 1, in 1963/64 made an attempt to obtain data on the effects of nonequilibrium flows on blunt bodies. This effort was limited by the CAL shock tunnel capability as well as the lack of diagnostic methods to obtain experimental information on the tunnel ambient species concentration. Experiments at CAL with a large wedge-flat plate model were interpreted to show a significant nonequilibrium effect on the afterbody pressure. Another conclusion was that the afterbody pressure of this model was very sensitive to ambient species concentration. From experiment and analysis it was concluded that an ambient dissociation of 3% existed in the tunnel and caused a 50% change in afterbody pressure. At the time of the experiments no diagnostic procedure was available to experimentally confirm the amount of dissociation. Other shortcomings were limited altitude, Reynolds number and velocity ranges. In summary, the investigation did not result in absolutely reliable and comprehensive data.

With the development of Tunnel J, designed specifically for the study of real gas effects, for the first time an opportunity is provided to conduct a comprehensive study of the real gas effects problems. No other ground test facility exists which has this capability. In addition it is quite fortunate that during recent years diagnostic techniques have been developed at AEDC which make it possible to reliably determine the chemical composition and state of the test gas in addition to the dynamic properties of the test section flow.

Studies conducted to date, Refs. 3 and 4, have demonstrated that the Tunnel J facility has the capability of providing three basic flow environments suitable for conducting hypersonic aerodynamic tests. These test conditions include (1) high Reynolds number ideal gas flows, (2) high enthalpy equilibrium gas flows, and (3) thermochemical nonequilibrium gas flows. Tunnel J has undergone extensive hardware and electrical modification in FY 72 and FY 73. At the beginning of FY 74 the facility will be equipped with two 20-inch diameter test sections and an isolated model support. Tunnel J can be operated in two different modes producing different test capabilities. In Mode I it operates as a shock tunnel, in Mode II as an MHD augmented facility. The following are typical test flow conditions for the two modes:

Mode I

State of test gas:	Ideal and Real Gas in Equilibrium
M_∞ test Mach number	6 to 14
M_S driven tube	2.5 to 6
Driver gas	N_2, He or mixture
Test gas	N_2 or air
Test section diameter inches	20
P_O max psia	35,000
T_O °K	900 to 3500
Re/ft max (at M_∞ = 8)	200×10^6
Test time msec	2.5 to 10

Mode II

State of test gas:	Real gas, equilibrium and nonequilibrium
M_∞	10
U_{lim} max flow velocity ft/sec	20,000
M_S	8
Driver gas	He
Test gas	Air
Test section diam. inches	20
P_O max psia	22,000
T_O °K	5,000
Density Altitude for M = 10	145,000 ft
Test time, msec	2.5

Figs. 1 and 2 show the operating envelopes of Modes I and II.

Previous work has resulted in the development of computer programs for treating the real gas flow regime. These will be used in conjunction with the experimental program.

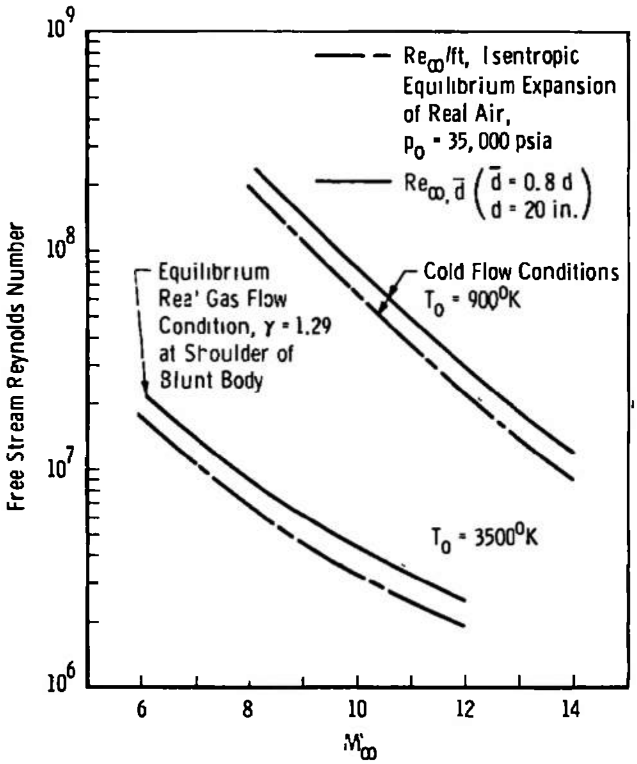


Fig. 1 Mach Number - Maximum Reynolds Number Capability of Tunnel J, Mode I (Tailored Interface)

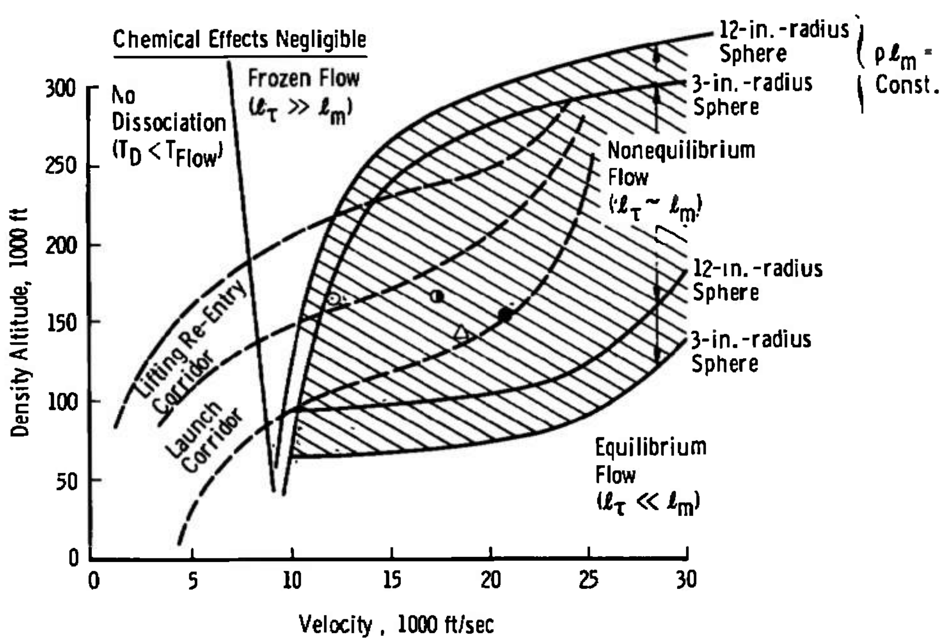


Fig. 2 Aerodynamic Testing Regimes with MHD Augmentation, Mode II

2. APPROACH

The approach will be as follows:

a. Complete the required surveys and flow calibrations of Tunnel J to obtain the information for the identification of the state of the gas and the dynamic properties of the test section flow field. This information will be required as input into the data analysis and computer programs.

b. Use available or modified computer programs to predict the real gas effects on model data as listed under specific objective. Compare analytical data with experimental results as well as data taken under real gas with data obtained under ideal gas conditions. Compare with flight results when they become available.

REFERENCES

1. Vidal, R. J., "High Temperature Phenomena in Hypersonic Flows", AEDC-TDR-64-143 (AD601605), June 1964.

2. Nagel, A. L. and Thomas, A. C., "Analysis of the Correlation of Wind Tunnel and Ground Test Data to Flight Test Results," AIAA Paper No. 65-208, AIAA Flight Testing Conference, Huntsville, Ala, Feb 15-17, 1965.

3. Pate, S. R., Siler, L. G., Stallings, D. W., and Wagner, D. A., "Development of the AEDC-VKF Tunnel J - A Real Gas High Density, True Velocity, Hypersonic, Aerodynamic Test Facility, AIAA Paper No. 72-993, AIAA 7th Aerodynamic Testing Conference, Palo Alto, Calif, Sep 13-15, 1972.

TO NO. 3: WIND TUNNEL FLOW QUALITIES AND EFFECTS ON TEST RESULTS

OBJECTIVE

1. General. To define and improve the quality of flow in wind tunnels.

2. Specific. The requirements for improved accuracy of steady state and dynamic data from wind tunnels and the expanded test requirements in dynamic investigations into the areas of engine inlets, flutter, buffeting, pulsating shocks, and aerodynamically induced noise have resulted in increased emphasis in flow equality. In addition, the significant improvements in instrumentation and data systems over the past few years have resulted in uncovering imperfections in tunnel flow, which previously were too small to measure. Therefore, the specific items of concern regarding the tunnel environment include: (a) free-stream acoustic disturbances, (b) free-stream velocity fluctuations, (c) flow angularity, and (d) flow contaminants.

TECHNICAL APPROACH

The basic assumption in wind tunnel testing is that blowing air over a stationary body (the wind tunnel) is equivalent to a moving body traveling through stationary air (free flight). The validity of this assumption and thus the accuracy of the free flight simulation in a wind tunnel is dependent upon the quality of flow in the test section. In the present context, the term "flow quality" refers to the test section environment, independent of the presence of a test model. Therefore, to define and improve the tunnel environment, the following investigations are needed.

a. Free-Stream Acoustic Disturbances. The wind tunnel noise which is radiated primarily from the test section boundaries and compressor is known to greatly affect the transition Reynolds number. Recent results from supersonic and transonic wind tunnels indicate that there is a substantial reduction in transition Reynolds number due to tunnel noise. In general, the transition Reynolds number decreases with increasing unit Reynolds number at subsonic Mach numbers; whereas, the transition Reynolds number increases with increasing unit Reynolds number at supersonic Mach numbers. Supersonically, this effect was attributed to the turbulent boundary layer noise. However, recent data obtained in ballistic ranges has also shown this apparent unit Reynolds number effect in the absence of turbulent boundary layer noise. These

perplexing results need to be investigated in detail to define more precisely the freestream acoustic environment, determine the magnitude of its effect on test results, and ultimately improve the flow quality in existing wind tunnels.

b. Free-Stream Velocity Fluctuations. The velocity fluctuations (i.e., vorticity) present in the test flow can also influence the boundary-layer state on the model. The effects of wind tunnel unsteady flow environment on boundary-layer transition location on a model have been demonstrated. In addition, transition length data obtained in various transonic wind tunnels indicate that the distance between laminar flow breakdown and fully developed turbulent flow is affected by the magnitude of free-stream disturbances. This raises the possibility that free-stream flow unsteadiness could affect the structure of the turbulent flow itself. There are no data to date which either confirm or refute the significance of this type of interaction, particularly in the transonic flow regime. Since the turbulent structure affects important aerodynamic parameters, it is important to determine if this type of interaction is significant and the extent of its significance. Measurements of the free-stream velocity fluctuations (three components) should be obtained from as many points in each tunnel circuit as is feasible in order to document and define the test flow quality. Hot wire, hot film, and laser doppler velocimeter techniques could be used to obtain the velocity fluctuation.

c. Flow Angularity. The criteria for evaluation of steady state flow quality are well established when considering parameters such as flow angularity or transition Reynolds numbers. The criteria used for evaluating flow angularity are based on the precision to which a model or measuring probe angle of attack can be set. The current limit of the precision of angle measuring devices is about ±0.05 degrees. Efforts are underway to increase the precision of model angle of attack measurements to about ±0.01 deg. An effective technique for reducing flow angularity is the installation of a honeycomb in the stilling chamber. However, there is a lack of criteria for the selection of honeycombs.

d. Flow Contaminants. Boundary layer characteristics can be of primary importance during wind tunnel tests. Since the boundary layer is affected by model surface conditions which in turn are affected by tunnel particulate concentration, particulate effects need to be evaluated.

The mixture of water vapor and air in wind tunnel tests is known to produce condensation shocks in the vicinity of shock waves on bodies and airfoils. Many wind tunnels are operated with sufficiently dry air

to be free of condensation conditions, some with the aid of air dryers. However, there have been many instances where wind tunnel data were questioned due to the large moisture content in the test section. Therefore, definitive studies are needed to determine the effects of condensation on pressure or force data obtained in transonic and supersonic wind tunnels.

REFERENCES

1. Credle, O. P. "Evaluation of the Acoustic Silencer in the AEDC-PWT 4-Ft. Transonic Tunnel," AEDC-TR-68-234 (AD841857), October 1968.

2. Credle, O. P. "An evaluation of the Fluctuating Airborne Environment in the AEDC-PWT 4T Transonic Tunnel," AEDC-TR-69-236 (AD861673), November 1969.

3. Credle, O. P. "Evaluation of the Overall Root-Mean-Square Fluctuating Pressure Levels in the AEDC PWT 16-Ft. Transonic Tunnel," AEDC-TR-70-7 (AD864827), February 1970.

4. Credle, O. P. and Carleton, W. E. "Determination of Transition Reynolds Number in the Transonic Mach Number Range," AEDC-TR-70-218 (AD875995), October 1970.

5. Anderson, C. F., Anderson, A., and Credle, O. P. "The Effect of Plenum Volume on the Test Section Flow Characteristics of a Perforated Wall Transonic Wind Tunnel," AEDC-TR-70-220 (AD876366), October 1970.

6. Credle, O. P. "Perforated Wall Noise in the AEDC-PWT 16-Ft. and 4-Ft. Transonic Tunnels," AEDC-TR-71-216 (AD888561), October 1971.

7. Lowson, M. V., "Prediction of Boundary Layer Pressure Fluctuations," AFFDL-TR-167, April 1966.

8. Brown, G. B., "The Vortex Motion Causing Edgetones. The Proceedings of the Physical Society, Vol. 49, Pt. 5, pp. 498-507, Sept. 1937.

9. Dods, J. B. and Hanly, R. D. "Evaluation of Transonic and Supersonic Wind Tunnel Background Noise and Effects of Surface Pressure Fluctuation Measurements." AIAA Paper No. 72-1004, AIAA 7th Aerodynamic Testing Conference, Palo Alto, CA, Sept. 13-15, 1972.

10. Mabey, D. C. "Elimination of Edge-Tones in the Perforated Working Section of the 3 ft x 3 ft Tunnel at R.A.E. Bedford, 32nd Semiannual Meeting of Supersonic Tunnel Association, Sept. 1969.

11. Mabey, D. G. "Flow Unsteadiness & Model Vibration in Wind Tunnels at Subsonic and Transonic Speeds," R.A.E. Tech. Rept. 70184, 1970.

12. Carriere, Pierre, and Chevallier, Jean-Pierre. "Recent Progress in the O.N.E.R.A. Hot-Shot Wind-Tunnels," Fifth Hypervelocity Techniques Symposium, pp. 29-324, University of Denver, March 1967.

13. Potter, J. L. "Some Special Features of Boundary Layer Transition on Aeroballistic Range Models," presented to Boundary Layer Transition Specialist Workshop, Aerospace Corporation, 1971.

14. Woolley, J. P., and Karamcheti, K. "A Study of Narrow Band Noise Generation by Flow Over Ventilated Walls in Transonic Wind Tunnels," AFOSR-TR-73-0503, February 1973.

15. Pate, S. R. and Schueler, C. J. "Radiated Aerodynamic Noise Effects on Boundary-Layer Transition in Supersonic and Hypersonic Wind Tunnels." AIAA Journal, Vol. 7, No. 3, March 1969.

16. Potter, J. Leith "Observations on the Influence of Ambient Pressure on Boundary-Layer Transition." AIAA Journal, Vol. 6, No. 10, October 1968, pp. 1907-1911.

17. Lumley, J. L. "Passage of a Turbulent Stream Through Honeycomb of Large Length-to-Diameter Ratio." ASME-JOBE, June 1964.

18. Bossel, Hartmut. "Flow Studies and Turbulence Measurements in the Hesse 6-Inch Supersonic Wind Tunnel." Report No. AS-67-2, February 1967, College of Engineering, University of California, Berkeley, California.

19. Morkovin, M. V. "Critical Evaluation of Transition from Laminar to Turbulent Shear Layers with Emphasis on Hypersonically Traveling Bodies." AFFDL-TR-68-149, March 1969.

20. Laufer, John "Aerodynamic Noise in Supersonic Wind Tunnels," Journal of the Aerospace Sciences, Vol. 28, No. 9, September 1960.

21. Boone, J. R., and McCanless, G. F., Jr. "Application of the Techniques for Evaluating the Acoustic Sources of Background Noise in Wind Tunnel Facilities." Technical Report HSM-R05-69, Chrysler Corporation Space Division, March 1969.

22. Burgess, Warren C., Jr., and Seashore, Ferris L. "Criterions for Condensation-Free Flow in Supersonic Tunnels," NACA TN 2518, December 1951.

TO FOCAL POINT

C. Tirres, Capt, USAF
DYR, Tel 455-2611 (ext 7835)

TO NO. 4: CRYOPUMPING AND CRYODEPOSITS OF ROCKET EXHAUST GASES AND PROPELLANTS IN HIGH VACUUM CHAMBERS

OBJECTIVE

1. General. The general objectives are to determine the physical properties and the behavior of rocket exhaust gases and hypergolic fuels and oxidizers and their deposits on surfaces at cryogenic temperatures and high vacuum, and to improve techniques for pumping exhaust gases and propellants including hydrogen in high vacuum chambers.

2. Specific.

a. Physical properties of cryodeposits.

The physical properties and behavior of cryodeposits must be determined as they accumulate on various cryogenic surfaces such as wall panels, mirrors, filters, and lenses in space simulation chambers. The effects of the deposits on the properties of optical components and means for their reduction or elimination must be studied.

b. Cryopumping of exhaust gases and hypergolic propellants.

Cryopumping is a widely accepted and practical method of removing exhaust gases from high vacuum chambers in cases when rocket engines are in operation. Occasional misfires of rockets being tested in cryopumped chambers result in either fuel or oxidizer or both being condensed on the cryopanels and other cold surfaces in the chamber. If an engine using hypergolic propellants should misfire, the propellants would condense on the cryopumping surfaces, creating a potentially hazardous situation. A chemical reaction between the deposited fuel and oxidizer may overload the refrigeration system possibly resulting in liquefaction and vaporization of the solid deposit, a rapid repressurization of the chamber and perhaps ignition of the propellants. The properties and behavior of propellants under these conditions must be investigated and necessary safeguards against these hazards established.

c. Cryopumping of hydrogen.

Vacuum pumping of hydrogen in large amounts is still a problem under certain conditions. The method of continuing interest is hydrogen pumping by cryosorption. Since present sorption methods and sorbents used have significant shortcomings new sorbents and techniques to cryopump hydrogen must be investigated and developed.

TECHNICAL APPROACH

1. PRESENT STATUS

a. Physical Properties of Cryodeposits.

Cryopumping is used extensively in vacuum chambers. When the gas loads are relatively small, cryodeposits accumulated on cryopanels and cooled optical components are small, perhaps several microns thick. For these conditions no significant problems except optical contamination have been encountered. However as larger gas loads had to be handled by the system several additional problems have been observed on cryopanels and optical components. Some of these problems are:

(1) Cryodeposits occasionally peel from the cryosurface.

(2) Cryodeposits delaminate and separate from the surface as a single large sheet.

(3) Cryodeposits change from a clear glassy appearance to a porous opaque layer.

(4) A cryodeposit of hydrogen will adhere to a previously deposited argon layer on a 4.2°K surface. However, an argon cryodeposit will not adhere to a previously deposited hydrogen layer on the same 4.2°K surface.

(5) Cryodeposits of CO_2 formed at 20°K are much better sorbents for H_2 than those formed at 40°K and then cooled to 20°K.

The behavior of the cryodeposits as described above has been observed but the underlying physical properties and parameters involved are still unknown. To achieve the necessary understanding of the phenomena the physical properties of the various gases and cryodeposits must be studied as a function of the environmental and test parameters.

b. Cryopumping of exhaust gases and hypergolic propellants.

Normally the gases condensed on the cryopanels of vacuum chambers in which rockets are operated are the combustion products and present little problem at the end of the test when the cryogenic panels are slowly warmed up and the gases are released. However, if an engine using hypergolic propellants misfires, the hypergolic fuel and oxidizer will condense on the cryopanels and create a potential hazard. Reactions between fuel and oxidizer may occur and possibly lead to ignition. Little is known about the reaction rates of hypergolic mixtures at

cryogenic temperatures and the effect of low pressure on the reaction process, in particular reaction rates and propagation. Tests have been conducted with small engines using hypergolic propellants without any apparent problem. As larger engines will be tested in the future, however, a definite need exists to investigate possible problems and hazards which may be encountered.

c. Cryopumping of hydrogen.

Cryopumping of hydrogen by sorption is of continued interest because it offers a more economical method than the more conventional cryopumping at liquid helium temperatures. Two types of sorbents have been used. The first is represented by charcoal and the molecular sieves. These sorbents are located in the vacuum chamber and are coated or packed into cooled cryopanels or trays. It is usually necessary to bake them out prior to use and then cool them down when they are to adsorb the H_2. Once they are saturated, the test must be terminated and the sorbents must once again be baked out to reactivate them. This system has the disadvantage of poor thermal contact between the bulk of the sorbents and the actively cooled panels or trays.

The second sorbent is represented by a cryodeposit of gases such as CO_2. These sorbents are metered into the vacuum system after the cryopanels are already cold. They form a cryodeposit at the temperature of the panel and thus do not require a long cooldown period. Their disadvantage is that they also collect on any other cold surface in the test chamber. Thus, if there are cold optical surfaces involved in the test, the CO_2 sorbent becomes a contaminant on these surfaces.

2. APPROACH

a. Physical properties of cryodeposits.

There are several methods of determining the crystalline structure of materials. These involve using protons, x-rays, electrons or neutrons as the incident radiation and determining diffraction patterns. Commercial instrumentation is available for each of these methods. However, because of the nature of cryodeposits and the conditions under which they are formed, it is expected that standard equipment must undergo modification to meet specific AEDC needs. Since cryodeposit structures may be unstable two properties of cryodeposits which have been studied in some details at AEDC (reflectance and adsorption capacity) would serve as adequate indicators of any disturbance of the cryodeposit structure caused by the application of the above test methods.

The experimental procedure would consist of measuring the reflectance and adsorption properties before and after exposing the cryodeposit to the particular radiation levels deemed appropriate for diffraction studies. Such tests with x-rays, electron beams and proton beams would establish the levels of radiation that cryodeposit structures can withstand.

From these results, the most appropriate method of diffraction technique can be chosen and appropriate modifications of commercial equipment made to determine the nature of the crystalline structure of cryodeposits.

Once the equipment is available to diagnose the nature of the cryodeposit, then such variables as molecular strike rate, cryosurface temperature, substrate material, mixed gas species, etc, can be investigated in relation to the behavior and effects of the deposits on cryopanels and optical components.

b. Cryopumping of hypergolic fuels and oxidizers.

To determine the properties and behavior of hypergolic propellants under conditions of condensation on cryopanels and low pressure, the following approach may be taken:

The reaction rates and heats of reaction can be determined experimentally in a small research vacuum chamber. The experimental approach would be to cool a section of cryopanel to the required temperature in a chamber that is adequately instrumented to determine the heat load, the chamber pressure, and the fuel and oxidizer addition rates. A typical test sequence would consist of predepositing a known quantity of fluorine into the chamber and cryopumping it on the cooled surface. Hydrogen would then be admitted to the chamber in controlled quantities. After each addition, the heat load on the refrigerator would be monitored to determine the reaction rate. Such experiments would be repeated with various cryodeposit temperatures and gas addition rates. Candidate fuel and oxidizer combinations are hydrogen-fluorine, ammonia-fluorine and hydrazine-perchloryl-fluoride.

c. Cryopumping of hydrogen.

Recent articles in the literature suggest that anodically oxidized aluminum cryosurfaces may be used at cryogenic temperatures to adsorb hydrogen. Extensive work has been done at AEDC on methods of etching and anodizing aluminum surfaces to reduce the reflectance of infrared radiation from chamber walls. Sufficient experience in this area prompts

the suggestion that deep etching and heavy anodizing may produce a sufficient layer of sorbent to make this technique a practical pumping system for hydrogen. It would have the advantage of intimate thermal contact with the refrigerant gas and avoid the problems of contamination presented by the cryodeposit sorbents. The experimental approach would require evaluation of various techniques of surface preparation by conducting adsorption isotherm tests on sample specimen.

REFERENCES

1. Haygood, J. D. and Dawbarn, Ron, "Helium Pumping by 4.2°K Cryodeposits." AEDC-TR-66-204, AD543411, January 1967.

2. Dawbarn, R., "Cryosorption of H_2 by 12-20°K CO_2 Deposits." AEDC-TR-67-125, AD655067, July 1967.

3. Dawbarn, R., "Development and Evaluation of a Cryosorption Pump Capable of Pumping He." AEDC-TR-68-205, AD841628, October 1968.

4. Wood, Bobby E., "In Situ Measurement of Thickness and Other Properties of Carbon Dioxide Cryodeposits by Optical Techniques." AEDC-TR-67-226, AD662869, December 1967.

5. Southerlan, R. E., "10-22°K Cryosorption of Helium on Molecular Sieve 5A and Hydrogen on Condensed Vapors." AEDC-TR-65-49, AD463339, May 1965.

6. Dawbarn, R., Busby, M. R., and Kinslow, M., "Study of High Energy Gases Impinging on Various Cryosurfaces." AEDC-TR-72-33, AD740548, April 1972.

7. Tempelmeyer, K., "A Summary Report of the Cryosorption Pumping of Hydrogen by CO_2 Frost." AEDC-TR-70-123, AD707844, June 1970.

TO FOCAL POINT

E. L. Hively
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 5: RADIATION AND COMBINED ENVIRONMENT TESTING IN HIGH VACUUM CHAMBERS

OBJECTIVE

1. General. The overall objective of work in this area is to improve the AEDC high vacuum chamber capabilities in long wavelength sensor testing and to continue to investigate new equipment and testing techniques. As sensor technology improves, new and increased sensitivity test equipment and better test techniques will be required to test the advanced sensors for satellite sensor evaluation in AEDC ground test facilities.

2. Specific.

a. Improve AEDC vacuum chamber 7V IR capabilities.

b. Develop Far Infrared Reflectometer.

c. Evaluate cryogenic optics transmission.

d. Detect and identify the optical properties of sensor optical component.contaminants.

e. Upgrade space and nuclear combined environment testing.

TECHNICAL APPROACH

1. Improved IR Testing. The current applications of thermal radiative techniques to studying persistent problems associated with 7V sensor testing will be continued. This includes determining the off-axis rejection of mirrors used in the infrared and also development of a multiple mobile target system for sensor tracking tests. Blackbody development and calibration efforts will also be continued. It is expected that other problems will emerge in this area as future sensor tests are encountered.

2. Development of a Far Infrared Reflectometer. Since the trend in sensor testing is toward a completely black and completely cold background, surface emittances will have to be considered. For wall temperatures of 77 to 20°K this means spectral emittance measurements would cover the wavelength range from about 50-200μ. This will require investigation and development to modify the ellipsoidal mirror reflectometer currently being assembled.

3. Transmission of Condensation Contaminated Optical Components at Cryogenic Temperatures. Transmission of windows, lenses and other optical components may change considerably because of gas condensation when cooled to low temperatures. Star temperature measurements, satellite windows, space telescopes, manned spacecraft, and many other applications are hindered with this problem. The problems vary according to film thickness and structure of the condensed gas and depend on wavelength, the condensed species and the temperature and pressure at which deposition occurred. In some instances the total transmission can be changed due to thin film interference, but usually the most troublesome aspect is the reduction in image quality caused by scattering through the condensed layer. Capabilities need to be developed for making these measurements in the ultraviolet, visible, and infrared.

4. Detection, identification, and optical properties of sensor optical component contaminants. The quantitative detection and/or identification of contaminants is a problem of vital concern in the evaluation of tests involving low temperature optics and sensors. Currently, infrared techniques appear promising in this area; however, other techniques may evolve to be evaluated. This work should be continued until an adequate method is found to support testing in this area.

Optical properties of CO_2 and H_2O deposits that were condensed on a cryogenic surface have been determined previously in the visible and near-infrared. The properties included refractive index, scattering coefficient, and absorption coefficient. The measurement capabilities should be extended into the infrared to include both real and imaginary portions of the refractive index since absorption can no longer be neglected. The optical properties of other contaminants should also be studied.

5. Space and Nuclear Combined Environmental Testing. This program is to upgrade the existing combined space environment test capability so that most normal testing requirements may be met. The equipment to accomplish this addition is available and attempts are being made to procure it. The equipment may be further utilized to produce a much needed nuclear combined environment test capability. This capability would be used to investigate synergistic effects in this test area and to provide nuclear hardening tests in the sensor and other related fields.

REFERENCES

1. Seiber, B. A., et al, Reflectances of CO_2 and H_2O Cryodeposits at Solar Wavelengths, AEDC-TR-71-241 (AD733326), November 1971.

2. Latture, N. C., DFVLR/AEDC Cooperative Thermal Test II, AEDC-TR-72-54 (AD740899), May 1972.

TO FOCAL POINT

Ules Lee Barnwell, Jr., Major, USAF
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 6: ANALYTICAL SUPPORT OF GROUND FACILITY TESTING

OBJECTIVE

1. General. To provide for the continued development of analytical techniques and computer programs for analyzing fluid dynamic phenomena encountered on the various types of aerodynamic and propulsion systems tested in the test facilities at the AEDC.

VKF

2. Specific. Certain types of flows are repeatedly encountered in ground test facilities used to support the development of Air Force weapon systems. Effective support of the AEDC testing mission requires accurate analytical prediction of these flows in order to design test installations, to design support equipment, to design and locate test instrumentation and to interpret test data. The problem areas of current interest include shock structure in plumes, turbulent near-wakes with large bleed flows, jet plume-external stream interactions, turbine engine exhaust nozzle thrust performance, unsteady flow fields under hypersonic conditions, dynamic stability, turbulent boundary layers with longitudinal and normal pressure gradients as well as mass injection, laminar and turbulent separated flows, boundary layer transition, and flow fields around blunt bodies in a supersonic free stream which has a nonuniform temperature profile.

TECHNICAL APPROACH

1. PRESENT STATUS

During the past several years, continued work in the area of analytical prediction techniques for complex fluid mechanical phenomena has been ongoing at the AEDC. The availability of the results of this work has proven most valuable in numerous applications. The following are representative examples of these applications:

a. Results from analytical solutions have been used to support and interpret the data from the wind tunnels; e.g., discrepancies between flight test results and wind tunnel results have been resolved.

b. Methods of scaling wind tunnel results to the flight conditions have been developed.

c. Prediction techniques for the repetitive shock structure in exhaust plumes have been developed to support IR radiation measurements of turbojet exhausts. This technique also has important applications in ducted flows with non-ideal supersonic central streams.

d. On many engine tests conducted at AEDC, there is a requirement that an analytical prediction of the engine thrust be made to further increase the confidence level of the approximately measured thrust level. To date, this work has provided the analytical tools necessary to verify the measured thrust performance on engines such as the TF-30, J-57, GE-F-100, and PW-F-100.

2. APPROACH

There is a definite requirement for the continued development of digital computer programs for analyzing the complex flow fields encountered in flight as well as in test facilities if one hopes to obtain an understanding of the phenomena in sufficient depth to plan sound and meaningful test programs and to correctly interpret the test data.

In the future considerable research effort will be expended in the following problem areas:

a. Unsteady Aerodynamic and Dynamic Stability - Continued development of analytical capabilities for the analysis of hypersonic, inviscid, unsteady flow fields of interest relative to AEDC dynamic stability testing. Primary emphasis will be on developing and evaluating a perturbation scheme for calculating unsteady, inviscid flow fields for a cone with either a sharp or a blunt nose.

b. Laminar Separated Flows - Formulation of accurate implicit finite-difference techniques for solving the complete compressible Navier-Stokes equations for separated flow fields including shock-boundary layer interactions. The first step in this effort will be the development and evaluation of implicit integration techniques for the Navier-Stokes equations which are nonlinear partial differential equations.

c. Blunt Body Flow Field with Nonuniform Temperature Profiles in the Free Stream - Continued development of the arc-heated cold shroud flow facility has created a requirement to develop analytical techniques for calculating the flow field around blunt bodies in a supersonic free stream which has a nonuniform temperature profile. An existing computer program for the solution of the flow about an axisymmetric blunt body at angle of attack will be modified to treat the cold shroud flow field. If deemed necessary to obtain an adequate understanding of the cold shroud flow field, the development of additional analytical techniques will be initiated.

d. Exhaust Nozzle Aftbody and Boattail Flow Fields - This effort will be concentrated on the problem areas associated with aftbody and boattail flow separation or abnormally thick turbulent boundary layers where significant viscous/inviscid interaction exists and the usual viscous/inviscid numerical calculation cycle cannot be used to make first order corrections to effective body displacements. Several tools are available for making theoretical predictions of the inviscid and viscous flow fields, both external and internal, but the interaction cycle for correcting body displacements when a strong interaction exists is not understood at present. This effort will be directed toward conditions where the boundary layer is turbulent and the free stream is subsonic, transonic, or supersonic.

e. Three-Dimensional Flow Field Computations - New computer programs to calculate three-dimensional transonic and supersonic flow fields will be developed. Existing AEDC time-dependent transonic flow analysis will be extended to consider three-dimensional flows. The formulation of the governing equations for the case of transonic flow must be such that the computational requirements are compatible with AEDC digital computing hardware. The approach used by the General Applied Sciences Laboratory in the application of the three-dimensional method of characteristics solution technique for supersonic external flow over a body in an infinite system will be followed in developing a new computer program for both supersonic internal and external flows having either solid wall or constant pressure boundary conditions.

REFERENCES

1. Adams, John C., Jr. and Martindale, William R., "Hypersonic Lifting Body Windward Surface Flow-Field Analysis for High Angles of Incidence," AEDC-TR-73-2 (AD756499), February 1973.

2. Mayne, Arloe Wesley, Jr., "Analysis of Laminar Boundary Layers on Right Circular Cones at Angles of Attack, Including Streamline-Swallowing Effects," AEDC-TR-72-134 (AD750130), October 1972.

3. Adams, J. C., Jr., "Analysis of the Three-Dimensional Compressible Turbulent Boundary Layer on a Sharp Cone at Incidence in Supersonic and Hypersonic Flow," AEDC-TR-72-66 (AD743003), June 1972.

TO FOCAL POINT

Elton R. Thompson
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 7: ABLATION AND EROSION TESTING TECHNIQUES

OBJECTIVE

1. General. Reentering projectiles from ballistic missiles are subjected to high enthalpy and high pressure. In some cases an erosive aspect is added to this already hostile environment. To study these combined environments a facility that provides high enthalpy and pressure, and simultaneously provides the erosive medium is needed. Erosive mediums such as dust, rain, snow, and clouds are all of interest.

2. Specific.

Model Stagnation Conditions

Enthalpy (Btu/lb_m)	Pressure (atmosphere)
6,000 - 9,000	100 - 200

Erosive Environment

Dust (1-1000 micron particles with 15,000-20,000 fps velocities)
Rain
Snow
Clouds

TECHNICAL APPROACH

1. Aeroballistic Range. This facility provides the required enthalpy and pressure for RV ablation testing. The inclusion of erosive environments is continually being developed. Good production and characterization of dust, rain, snow, and clouds are all feasible. The greatest detriment to this type testing, other than short test exposures, has been the poor collection of data from the test specimen, which normally does not survive.

A guided track and recovery system (GTRS) has been developed by McDonnell Douglas for AEDC. In late FY 73 a projectile was successfully launched, guided, and recovered at a velocity of 17,000 fps. A 100-foot track is to be developed in FY 74 to study the track-model interactions. The pilot track is only 6 feet in length. A guided track of 1,000 feet in the 1,000-foot aeroballistic range could provide meaningful ablation and erosion data in a well characterized (as opposed to the poorly characterized erosive fields of flight test) erosive environment.

With the GTRS, the model has a known flight path, enhancing in-flight data collection and the RV model is recovered adding post flight data and the possibility of reflight of the RV model.

2. Arc Heated Ablation/Erosion Test Techniques. Testing in a GTRS facility would be the final step in the development and selection of ablation material for reentry vehicles. Initial development should be done in the arc heated ablation facility described elsewhere in this document under "Heaters for Ablation Facilities". Methods of providing an erosive environment to an RV model while it is ablating in an arc heated flow are being investigated. Techniques to be analytically considered include light gas gun accelerated particles; shaped charge accelerated particles; light gas Gatling gun accelerated particles; and aerodynamic drag accelerated particles. Both the acceleration of the particles to the required velocities and the directing of the particles onto an ablating RV model are areas of technical difficulty to be examined.

TO FOCAL POINT

Ules L. Barnwell, Jr., Major, USAF
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 8: TRANSONIC TESTING TECHNIQUES

OBJECTIVE

1. General. To advance transonic testing techniques and to improve the quality of data produced in present and future transonic wind tunnels.

2. Specific. Testing techniques and data quality of present transonic wind tunnels have become inadequate as a result of the closer design margins required for the development of current and future aircraft. The increased emphasis on transonic flight for large transport aircraft and air superiority fighters which must maneuver at transonic speeds for extended periods of time has amplified the limitations of existing transonic wind tunnels. These limitations include (a) wind tunnel boundary interference, (b) Reynolds number and scale effects, and (c) model support interference.

TECHNICAL APPROACH

1. Wind Tunnel Boundary Interference. The fundamental problems identified with boundary interference over the speed range of transonic tunnels are associated with: model blockage and induced upwash at subsonic Mach numbers, tunnel blockage in the vicinity of Mach 1.0, and reflection by the wall of model induced shock and expansion waves at low supersonic Mach numbers.

The present wall configurations are effective in eliminating the interference at subcritical and low supersonic flow conditions, but they are not suitable for near sonic conditions. Theoretical corrections have been successfully applied to lift interference data on simple bodies by using subsonic theory. However, corrections to pitching moment interference and lift interferences on more general models have not been successful. Therefore, theoretical and experimental studies are needed to develop improved wall boundary correction procedures for data taken from lifting models throughout the transonic Mach range and to develop improved wall configurations which will reduce wall interference effects.

2. Reynolds Number and Scale Effects. Existing transonic wind tunnels are not able to simulate flight Reynolds number for large aircraft of present and future interest. The differences in Reynolds numbers between the wind tunnel model and the prototype sometimes exceed

an order of magnitude, making extrapolation of wind tunnel data uncertain in predicting flight performance. Even when Reynolds number is duplicated for different scale models at a given Mach number, a scale effect on force and pressure data is observed when wall interference is believed to be insignificant. The cause of the apparent scale effect needs to be determined. Investigations are needed to develop boundary-layer scaling criteria for boundary layer shock wave interactions in two- and three-dimensional flows. Ultimately such criteria are needed for application to three-dimensional models with finite wing span or swept wings.

3. Model Support Interference. The model support interference is known to have large effects on the aerodynamic forces and moments of test models in the transonic flow regime. The work accomplished to date on support interference has been very specific with application only to a given model and to the wind tunnel where the work was performed. Therefore, the general guidelines for correcting the support interference effects are not applicable to all wind tunnels and model configurations. In addition, very little theoretical work has been accomplished on support interference at transonic Mach numbers because of an inadequate theoretical description of the flow fields.

Theoretical and experimental studies are needed to develop general guidelines for minimizing the effect of model support interference in transonic wind tunnels. Specifically, analytical capabilities are needed for use in assessment and correction of the support interference of any given test. The studies should include the interference effects in sting support mounts, wall support mounts (strut, half-model, etc.), and magnus rotors. In addition, the experiments should include investigation of new mounting arrangements and their interference effects on model pressure and force moment measurements.

REFERENCES

1. Pindzola, M. and Lo, C. F. "Boundary Interference at Subsonic Speeds in Wind Tunnels with Ventilated Walls," AEDC-TR-69-47 (AD687440), May 1969.

2. Lo, C. F. and Oliver, R. H. "Boundary Interference in a Rectangular Wind Tunnel with Perforated Walls," AEDC-TR-70-67 (AD704123), April 1970.

3. Lo, C. F. "Wind-Tunnel Wall Interference Reduction by Streamwise Porosity Distribution," AIAA Journal, April 1972.

4. Kraft, E. M. "Upwash Interference on a Symmetrical Wing in a Rectangular Ventilated Wall Wind Tunnel: Part 1 - Development of Theory," AEDC-TR-72-187 (AD757196), March 1973.

5. Glassman, H. N. "A Modification to the Method of Block Cyclic Reduction for Computing the Lift Interference in a Wind Tunnel with Perforated Walls," Masters Thesis, University of Tennessee, Knoxville, August 1972.

6. Binion, T. W., Jr. and Lo, C. F. "Application of Wall Corrections to Transonic Wind-Tunnel Data," AIAA Paper 72-1009, September 13-15, 1972.

7. Jacocks, J. L. "Evaluation of Interference Effects on a Lifting Model in the AEDC-PWT 4-ft Transonic Tunnel," AEDC-TR-70-72 (AD868290), April 1970.

8. Murman, E. M. "Computation of Wall Effects in Ventilated Transonic Wind Tunnels," AIAA Paper No. 72-1007, September 13-15, 1972.

9. Couch, L. M. "Transonic Wall Interference Effects on Bodies of Revolution," AIAA Paper No. 72-1008, September 13-15, 1972.

10. Monti, R. "Wall Corrections for Airplanes with Lift in Transonic Wind-Tunnel Tests," Report of the AGARD Ad Hoc Committee on Engine-Airplane Interference and Wall Corrections in Transonic Wind Tunnel Tests, AGARD-AR-36-71.

11. Bailey, F. R. and Steger, J. L. "Relaxation Techniques for Three-Dimensional Transonic Flow About Wings," AIAA Paper No. 72-189.

12. Ballhaus, W. F. and Bailey, F. R. "Numerical Calculation of Transonic Flow About Swept Wings," AIAA Paper No. 72-677, June 26-28, 1972.

13. Bailey, F. R. "Numerical Calculations of Transonic Flow About Slender Bodies of Revolution," NASA TND-6582, December 1971.

14. Newman, P. A. and Allison, D. O. "An Annotated Bibliography on Transonic Flow Theory," NASA TM X-2363, September 1971.

15. Cahill, F. and Cooper, B. L. "Flight Test Investigation of Transonic Shock-Boundary Layer Phenomena," AFFDL-TR-68-84, Vol. I, July 1968.

16. Stanerosky, E. and Hicks, G. "Scaling Effects on the Shock-Boundary Layer Interaction in Transonic Flow," AFFDL-TR-68-11, March 1968.

17. Loving, D. L. "Wind-Tunnel-Flight Correlation of Shock-Induced Separated Flow," NASA TND-3580, September 1966.

18. Love, E. S. "A Summary of Information on Support Interference at Transonic and Supersonic Speeds," NASA RML 53K12, January 1954.

19. Kurn, A. G. "Drag Measurements on a Series of Afterbodies at Transonic Speeds Showing the Effect of Sting Interference," RAE Technical Report No. 66298, September 1966.

20. Ericsson, L. E. and Reding, J. P. "Aerodynamic Effects of Bulbous Bases," LMSC-4-17-68-4, November 1968.

TO FOCAL POINT

C. Tirres, Capt., USAF
DYR, Tel. 455-2611 (Ext. 7835)

TO NO. 9: DYNAMIC STABILITY TESTING TECHNIQUES

OBJECTIVE

1. General. To improve, develop and validate techniques to measure dynamic stability parameters in subsonic, transonic, supersonic, and hypersonic wind tunnels.

2. Specific.

a. To develop techniques for making dynamic stability measurements of slender aircraft/missile shapes to high angles of attack.

b. To determine the validity of using the small amplitude technique for providing local, instantaneous damping derivatives.

c. To determine the effects of sting supports on dynamic stability measurements.

TECHNICAL APPROACH

1. The standard method for making dynamic stability measurements requires the mounting of the sting to support the model. In many cases, this is impractical or impossible. Small aircraft missiles, aircraft with no centerline body (F-14, F-15), configurations with boattails, bodies in close proximity of each other (space shuttle), aircraft/missiles at high incidence are all examples of configurations which present sting mounting difficulty. Alternate possible methods for supporting the model include ribbon supports and the half-model reflection plane technique. The latter technique has proven satisfactory for some applications. A problem that requires further investigation is the effect of the reflection plane boundary layer on the quality of the dynamic stability data. The quality of dynamic stability data is also affected by wall interference, Reynolds number, and scale effects. An orderly assessment of these effects is needed.

Measurements of cross derivatives such as yawing moment due to roll are non-existent and require development of new techniques.

2. Presently, in wind tunnel tests in hypersonic tunnels, the small amplitude technique is used wherein the model is positioned at a particular angular orientation to the free stream and the damping of a small amplitude oscillation is measured, providing a local effective damping derivative. The aerodynamic designer requires the local instantaneous

value. Hence, there is a question as to the relationship of the measured values to the local instantaneous values, especially for highly non-linear models.

An experimental investigation will be made on three aerodynamic shapes: linear (cone model), slightly nonlinear (a sphere-cone model), and highly nonlinear (a sphere-cone-cylinder-flare model). Effective local and roll-pitch-yaw damping data will be taken to provide the comparisons.

3. In all captive model techniques used for dynamic stability measurements, the effect of the model support on the derivatives must be determined. A system of oscillating a model without a physical support is required to evaluate the support effects. Magnetic suspension facilities have been developed for making static aerodynamic measurements (force, drag). The application of the magnetic suspension facility for making stability measurements needs to be developed to answer this question.

REFERENCES

1. Orlik-Ruckemann, K. J., Adams, P. A., Laberge, J. G., "On Dynamic Stability Testing of Unconventional Configurations," AIAA Paper 71-276, presented at 6th Aerodynamic Testing Conference, March 1971.

2. Billingsley, J. P., Norman, W. S., "Relationship Between Local and Effective Aerodynamic Pitch-Damping Derivatives as Measured by a Forced-Oscillation Balance for Preliminary Viking Configurations", AEDC-TR-72-25, AD741769, May 1972.

3. Burt, G. E., Uselton, J. C., "A Description of Two New Lifting-Body Forced-Oscillation Dynamic-Stability Test Mechanisms Recently Developed at AEDC." Paper presented at the Thirty-Eighth Semiannual Supersonic Tunnel Association Meeting, September 1972.

TO FOCAL POINT

Maurice A. Clermont, Major, (CF)
DYR, Tel. 455-2611 (Ext. 7835)

TO NO. 10: ROCKET AND ENGINE EXHAUST EMISSION DIAGNOSTICS

OBJECTIVE

1. General. The general objective is to develop reliable diagnostic techniques for determining accurate emission data from propulsion systems.

2. Specific.

a. Propulsion exhaust temperature, species concentration and spectral radiation measurement techniques must be developed to obtain complete exhaust emission information. This requirement includes turbine and rocket-propulsion systems and is specifically directed toward the development of diagnostic techniques which do not interfere with the exhaust flow or can be reliably corrected for such interference. Pollutant and/or radiating species of interest include NO, OH, NO_2, $C_x H_y$, CO, CO_2, SO, SO_2, H_2O, and HNO_3.

b. Techniques must be developed and applied to measure size, size distribution and concentration of solid or liquid particles in propulsion system exhaust plumes.

TECHNICAL APPROACH

1. PRESENT STATUS

a. Sampling Probe. The most often applied method for determining jet engine and rocket exhaust species concentrations, in particular pollutants, is by use of sampling probes which are inserted into the exhaust flow to extract gas samples for laboratory analysis, or to direct the exhaust sample through conditioned transfer lines to commercially available detection devices. Such systems make use of electrochemical, chemiluminescent, UV-absorption, or infrared absorption techniques for direct readout of the species and their concentration. The continuous, truly on-line sampling probe method, requires a probe, a transmission line and a pressure and temperature conditioning system for the gas sample. The probe method has the significant disadvantage that chemical reactions, e.g., recombinations or dissociations, can occur between the sampling point and the readout instrument, and thus affect the results with regard to the types of species and their concentration. The possibility of reactions is particularly important for measurements

of OH, NO, NO_2, NO_x, SO, SO_x, and hydrocarbons. As an example, (Ref. 1) with NO, an in situ noninterfering measurement has been made simultaneously with a sampling probe measurement. The result was that the NO concentration determined by the noninterfering ultra-violet narrow line absorption technique was much larger than the total of all oxides of nitrogen measured by the sampling probe. The exact source of the disagreement has not been objectively determined. The result, however, suggests that chemical reactions occurred in the sampling line. Although the sampling probe technique provides a relatively simple and routine approach to the problem, the uncertainty of possible chemical reactions in the transmission line will restrict or limit its application in certain cases. It is obvious that noninterference techniques are preferable and highly desirable.

b. Noninterfering Techniques.

(1) UV Narrow-Line Absorption and IR Emission-Absorption Techniques

A limited noninterfering spectroscopic capability has been developed at AEDC to measure temperature, spectral radiation and species concentration. Ultraviolet narrow line absorption has been used for the measurement of NO and OH. Infrared emission-absorption techniques have been applied for the measurement of CO_2 and H_2O. These spectroscopic techniques presently still suffer from complexity, low data production rate, extensive test time and detailed analysis when local values or radial temperature and concentration profiles are to be determined. The direct experimental results are lateral distributions of the emitted or absorbed integrated spectral intensities. They must be reduced to radial distribution by use of the Abel inversion method. Originally the method was developed for cases of complete axial symmetry of both the cross section and the radiance or temperature distribution of the source. The method has been extended to include sources of circular cross sections with slightly asymmetrical radiance distributions and also sources with only one mirror plane of symmetry. The most general case of asymmetry has not yet been applied. It is highly desirable to develop computational inversion procedures and computer programs for the generally asymmetric case. The elimination of some or all assumptions of symmetry however will require more test points, more complicated survey equipment, more complex computer programs and probably more computer time (Refs. 3-6).

Additional problems are connected with the radiation sources for the absorption techniques presently in use. For NO and OH measurements resonance line sources are in use, whereas for measurements of CO_2 and H_2O in the infrared region continuum sources are employed.

The IR and UV spectroscopic techniques must be further developed to automated systems for spatial scanning and to cover a wider range of species and potential applications in turbojet and rocket exhaust and other emission measurements of general interest.

(2) Laser Raman, Rayleigh and Mie Scattering Diagnostics

Besides the above mentioned noninterfering IR and UV emission and absorption diagnostic techniques the application of laser Raman spectroscopy for local gas temperature and concentration measurements of gas species has been demonstrated and applied by various organizations. Laser Rayleigh and Mie scattering have been applied to determine size and concentration of liquid and solid particles. For additional information on these techniques see References 7 and 8.

2. APPROACH

a. Sampling Probe. Recent results at AEDC indicate that chemical reactions may occur in the gas sample between the probe inlet and the detection device. It is, therefore, necessary to investigate the effects of the probe and transmission line on the species and their concentration. These effects are expected to be of particular importance in the measurement of NO, NO_2, NO_x, SO, SO_x, and the hydrocarbons. The approach for the investigation of the problem would be to use gas mixtures of known species concentrations to simulate test conditions and to determine chemical reactions and concentration changes in the transmission line upstream of the readout system. Various gas mixtures could be used to obtain information on specific reactions occurring, the sensitivity of individual species participating in these reactions and special handling and conditioning procedures required to eliminate or minimize the reactions. The goal is to establish criteria for the optimal design of the probe system and for estimating species concentrations at the source of the sample from the concentrations indicated by the readout system. The simplicity and ease of application of the online sampling probe technique justifies a thorough investigation and attempt to achieve this goal.

b. Noninterfering Techniques.

(1) UV narrow line absorption and IR-emission-absorption techniques.

The limited capability already existing at AEDC to measure NO, OH, CO_2, and H_2O must be extended to cover addition species

including CO, NO_2, C_xH_y, HNO_3, and possibly other species. Infrared emission-absorption techniques will be studied for CO, SO_2, and HNO_3. Ultraviolet narrow line absorption will be investigated for SO and wide band continuum absorption in the UV will be studied for NO_2 and SO_2 measurements.

Besides the extension to a larger number of species an automated system needs to be developed to increase data production rate and to facilitate operation and handling. This will include a spatial scanning system to determine radial distributions of species concentrations and temperatures.

The inversion method including computer programs for reducing the distributions of the integrated emitted or absorbed spectral intensities to radial distributions must be extended to the case of general asymmetry.

(2) Application of IR and UV Lasers to Spectral Absorption Techniques.

The present infrared emission-absorption techniques use continuum radiation sources. Application of tunable infrared lasers, being narrow line sources, will provide the advantage of greater spectral resolution, permitting unambiguous identification of such species as CO and hydrocarbons.

The required UV tunable laser for application to the spectral absorption method to measure NO, OH, and SO will have to operate in the ultraviolet region from 2000Å to 5000Å. Tunable lasers with sufficiently small bandpass are not yet available. They are however under development and expected to become available in the not-too-distant future. Utilization of these tunable lasers is expected to be the best approach to obtain concentrations of these species. The specific advantages of UV laser application are expected to be higher intensity and improved signal-to-noise ratio.

c. Interferometric Techniques. Interferometric spectral techniques may be used to measure in the far infrared region (10μ to 50μ) the concentration of HNO_3, hydrocarbons and other large molecules of interest. The method to be studied and developed would utilize either a Michelson type interferometer or a circular variable interference filter to obtain intensity measurements in absorption from which concentration data on the species of interest would be derived.

REFERENCES

1. McGregor, W. K., Seiber, B. L., and Few, J. D., "Concentration of OH and NO in YJ93-GE-3 Engine Exhausts Measured in situ by Narrow Line UV Absorption", presented at 2nd Conference on Climatic Impact Assessment Program, Cambridge, Massachusetts, Nov. 14-17, 1972.

2. German, R. C., et al, "Aircraft Turbine Engine Exhaust Emissions under Simulated High Altitude, Supersonic Free-Stream Flight Conditions", AIAA Conference on Environmental Impact, AIAA Paper 73-507 (1973).

3. Nestor, O. H., and Olsen, H. N., "Numerical Methods for Reducing Line and Surface Probe Data", Soc. Ind. Appl. Math. Rev. 2 200 (1960).

4. Freeman, M. P. and Katz, S., "Determination of a Radiance Distribution of an Optically Thin Radiating Medium", Journal of the Optical Society of America, Vol. 53, No. 10, Oct. 1963.

5. Olsen, H. N., et al, "Investigation of the Interaction of an External Magnetic Field with an Electric Arc", ARL Report 66-0016 (1966).

6. Benenson, D. M., et al, "Diagnostics on Steady State Cross-Flow ARCS", ARL 68-0109 (1968)

7. TO No. 12, Laser Raman Scattering Diagnostics

8. TO No. 13, Laser Rayleigh and Mie Scattering Diagnostics

TO FOCAL POINT

E. L. Hively
DYR, Tel. 455-2611 (Ext. 7835)

TO NO. 11: FLOW VISUALIZATION

OBJECTIVE

1. General. To develop new techniques and improve existing flow visualization techniques which can be applied to determine flow field and model surface parameters during wind tunnel testing and research.

2. Specific. Flow visualization techniques have been valuable aids in providing insight into various flow phenomena and model surface conditions. Included in these techniques are holography, photograph, thermographic paint techniques and infrared imaging. In the development and improvement of these techniques the following objectives are defined.

a. Extension of current holographic techniques should be made to determine density and pressure profiles in two-dimensional flow fields. Holograms can be reconstructed to produce high quality interferograms which can be analyzed to determine the density profile. These static density distributions could be converted to static pressure distributions in flows in which the total enthalpy remains uniform.

b. Extension of the current double pulsed holographic technique to a multiple pulsed system which will provide the capability for making a continuous series of holograms over a finite time interval is needed.

c. Optical scanning devices should be developed which would be capable of scanning interferograms produced from holograms. The goal is to automate data reduction techniques so that the basic information in a hologram can be digitized in relatively short periods of time. In the case of density measurements, an automatic technique for fringe counting and recording on magnetic tape or near instantaneous readout is needed.

d. In the application to the measurement of particle size and size distribution, an automatic technique for identifying particles of different sizes and recording the characteristics dimensions is needed.

e. More efficient techniques should be developed for reducing photographic information to produce heating rate data in methods which employ the phase change paint and thermographic phosphors. As in the holographic technique, an efficient and accurate method for digitizing optical data is needed.

f. Infrared scanning techniques should be evaluated to determine model surface temperature distributions. In this regard, the influence of the model material thermophysical properties, the influence

of the flow environment, the ability to convert analog data to digital data in short period of time and the accuracy limits of the technique for measuring temperature must be evaluated and determined.

g. Improvement in photographic data acquisition, resolution, processing and data reduction to support conventional flow visualization and model photography requirements.

TECHNICAL APPROACH

1. PRESENT STATUS

Present holographic techniques are capable of producing interferograms from which density profiles in axisymmetric flows can be computed. The orientation with respect to the model surface or with respect to the free-stream direction and the fringe spacing in the interferogram can be varied to optimize the sensitivity of the interferogram evaluation of the flow field density variations. The same hologram can be used to generate high quality conventional schlieren and shadowgraph pictures.

A double pulsed holographic system, which is capable of producing two holograms in millisecond time intervals, has been developed. This technique has been applied to the measurement of particle size, particle number density and particle velocity in flows with velocities up to 8, 000 ft/sec. The resolution on particle size is approximately 10 microns and above.

The phase change paint and thermographic phosphorescent techniques have been routinely applied to determine model surface heating rates. The phase change paint technique requires 15 minutes to record the data after model injection and approximately one day to reduce the data. The thermographic phosphorescence technique requires 5 minutes after model injection and approximately one week to reduce the data.

The IR imaging technique has not yet been applied at AEDC to the determination of model surface temperature distribution. An IR system should soon be evaluated.

2. APPROACH

The present holographic technique, which has been developed for the determination of density profiles in axisymmetric flow fields, will

be modified so that it will apply to two-dimensional flows. In addition, techniques for automatically reading the entire fringe pattern distribution generated by a hologram and converting this information into desirable flow field distributions will be developed. In this regard, an optical scanning technique will be developed and the data reduction procedures expanded.

Techniques for generating a train of controllable width and frequency light pulses from a laser will be investigated. Among those to be investigated will be the cavity dumping technique which will involve the use of a CW laser whose cavity will be modified to incorporate the cavity dumping concept. In this way, a CW laser is converted to a high power pulsed laser whose pulse width and repetition rate can be controlled. A means of recording pulse separations and reconstructing the holographic movies for data analysis purposes will also be studied. These recordings could then be applied to temporal studies of dynamic events.

An infrared scanning system for the measurement of aerodynamic heating rates on model surfaces will be defined and applied to determine model surface temperature distributions. An appropriate high speed, analog-to-digital conversion and recording system will be developed to provide computer generated data in a relatively short time. The relative accuracy and sensitivity of the system for temperature measurements will be determined by making comparisons with previously developed techniques, such as hot films, heat sensitive paints, etc. Calibrations to determine the thermo-physical properties of various materials will be made in a laboratory controlled environment. The capabilities and limitations of the technique for determining such things as transition and flow separation will be determined.

REFERENCES

1. Trolinger, J. D. and O'Hare, J. E., "Aerodynamic Holograph", AEDC-TR-70-44 (AD709764), August 1970.

2. Trolinger, J. D., Farmer, W. M., and Belz, R. A., "Holographic Techniques for the Study of Dynamic Particle Fields", Applied Optics 8 (1968).

3. O'Hare, J. E. and Trolinger, J. D., "Holographic Color Schlieren", Applied Optics, Vol. 8, October 1969.

4. Farmer, W. M., Burgess, K. S., and Trolinger, J. D., "Holocamera for Examination of Water Droplets in a Large High Altitude Test Cell", AEDC-TR-70-181 (AD715916), December 1970.

5. Clayton, R. M. and Wuerker, R. F., "Applying Holography to Reacting Spray Studies", Holographic Instrumentation Applications, NASA SP-248, January 1970.

6. Trolinger, J. D., "Holography for Aerodynamics," Astronautics and Aeronautics, Vol. 10, p. 56, August 1972.

7. Ragsdale, W. C., "Flow Visualization Workshop Report", NOLTR 72-94, May 1972.

TO FOCAL POINT

John R. Taylor, Major, USAF
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 12: LASER RAMAN SCATTERING DIAGNOSTICS (LRS)

OBJECTIVE

1. General. To apply, develop, and adapt the Smekal-Raman effect to the determination of the properties of flowing or condensed gases.

2. Specific

a. Gas Phase LRS Diagnostics

In continuous and pulsed wind tunnels, in engine test facilities, in engine and rocket exhaust and plume studies, in atmospheric pollution control and other technical areas the following gas properties measurements are candidates for the application of LRS diagnostics:

(1) Gas species identification and local concentrations of diatomic and multiatomic molecules, e.g., O_2, N_2, CO_2, CO, NO, H_2, F_2, HF, H_2O, and many others including free radicals such as CH and OH in high energy wind tunnel flows, jet engine and rocket exhausts, exhaust plumes and body flow fields.

(2) Local temperature.

(3) Identification of chemical reactions and determination of reaction rates in reacting gas mixtures.

(4) Species identification and concentration in atmospheric pollution.

(5) Local temperature and density fluctuations (turbulence) such as those occurring in wakes and jet mixing, e.g., rocket exhaust plume and external flow interaction flow fields.

(6) Utilization of the Raman scattered line width and shifts for obtaining values of translational velocity and temperature modes.

b. LRS Diagnostics of Solid Phase Species

Requirements for identification of molecular species in low density flows, e.g., far field nozzle exhaust plumes, cannot always be met using LRS in the gaseous phase because of low concentrations. In such cases the species can be determined by condensing the gas on a cryosurface and applying LRS. A possible typical example for the application of solid phase Raman spectroscopy is the identification of species and determination of time average production of contamination layers on cryogenically cooled sensors exposed to rocket exhaust gases.

There is also a requirement for the identification of highly reactive short life free radicals in exhaust plumes or other chemically reacting flows. The so-called "matrix isolation Raman spectroscopy" has a potential application to this problem.

c. Application

Application and adaptation of LRS to specific test problems and facilities.

TECHNICAL APPROACH

1. PRESENT STATUS

Species and their concentrations have been determined in pure gases as well as in multicomponent mixtures. Concentrations down to about 10^{17} moles/ccm of one particular species can be identified. Measurements have been achieved in mixtures of three components with concentrations between 10 and 50% with an accuracy of about 3%. These tests were conducted at room temperatures. Raman spectrum signatures of a number of diatomic and polyatomic molecules are known. For specific applications, others must be experimentally determined. These calibrations can be performed in transparent static cells filled with pure gas or a mixture. Most of the Raman spectra have been obtained at room temperatures. Relatively little is known about signatures at elevated temperatures. These signatures must be obtained by calibration using "hot cells". Hot cell experiments are now commencing.

LRS is also applicable to the determination of rotational and vibrational temperatures provided that these temperature modes are in local equilibrium. Local static gas temperature can be obtained from the ratio of intensities of Raman lines. The rotational structure of the Raman spectrum is normally used for this purpose since rotational degrees of freedom in most cases can be assumed to be in thermal equilibrium with the gas.

In air pollution measurements, the feasibility of monitoring gas pollutants at distances of about 600 ft has been proven for a number of gas species (N_2, O_2, H_2O, and CO_2) and concentrations. An experimental system is being developed at the AEDC to measure constituents of jet engine exhaust flows 6 ft downstream of the engine exit plane.

Using high powered pulsed lasers of 10 nanosec pulse width and a rate of 100 pulses per sec., it has been demonstrated that individual

species in a mixture can be identified and concentrations obtained during a single 10 nanosec pulse. By repeating this at the rate of 100 pulses per sec, the history of concentration changes was obtained.

In physical chemistry, laser Raman spectroscopy has been used for the identification of highly reactive, short lived gas species immobilized at cryogenic temperatures and imbedded in an inert condensed gas matrix to keep them from reacting with themselves. Identification has been achieved and time averaged gas phase concentration measurements may be feasible.

2. APPROACH

a. Continue to determine Raman spectrum signatures of pure gases and mixtures at room temperature and up to 1000°K. Examples of gas species are N_2, O_2, H_2O, CO, CO_2, NO, HF, NH_3, etc. Determine temperature effects on signatures. Investigate and assimilate theoretical and experimental data on Raman scattering cross sections and transition moments.

b. Determine and improve sensitivity of LRS and define density limitations for various gases. This will include investigation of laser frequency doubling to enhance sensitivity, and exploration of possible enhancement of sensitivity by tuning the laser frequency (tunable dye lasers) close to the resonance line of the observed specie.

c. Develop measurement of rotational and vibrational temperatures using continuous argon laser in combination with wide band spectral filters.

d. Study and develop possible applications of matrix isolation Raman spectroscopy for the identification of gas species condensed on cryogenic surfaces in AEDC facilities. Identify secondary effects of this procedure, such as the solid phase molecular Raman frequency shift, which have the potential of providing gas species concentrations.

e. Develop equipment, operation, installation procedures and data acquisition methods for specific application in AEDC continuous, pulsed and range facilities including Raman scattering measurements in jet and rocket engine exhausts.

REFERENCES

1. Herzberg, G., Molecular Spectra and Molecular Structure. Vol. I Spectra of Diatomic Molecules. D. Van Nostrand Company, Inc., Princeton, New Jersey, 1963.

2. Leonhard, D. A., "Feasibility of Remote Monitoring of Gas Pollutant Emissions by Raman Spectroscopy." AVCO-Research Report No. 362, December 1970.

3. Widhopf, G. F. and Lederman, S., "Specie Concentration Measurement Utilizing Raman Scattering of a Laser Beam." AIAA Journal, Vol. 9, No. 2, February 1971.

4. Hartley, D. R., "Experimental Gas Mixing Study Utilizing Raman Spectroscopy." AIAA 6th Aerodynamic Testing Conference, Albuquerque, N. M., March 1971.

5. Lapp, M., Penney, C. M., and Goldman, L. M., "Gas Analysis for Nitric Oxide by Raman Scattering." General Electric Report No. 71-C-211, July 1971.

6. Boiarski, A. A. and Daum, F. L., "Laser Raman Spectroscopy - A New Technique for Flow Field Analysis." Presented by 36th Semi-Annual Meeting of Supersonic Tunnel Association, NASA Marshall Space Flight Center, 7-8 October 1971.

7. Hartley, D. L., "Transient Gas Concentration Measurements Utilizing Laser Raman Spectroscopy." AIAA Journal. Vol. 10, No. 5, May 1972.

8. Salzman, Masica, W. J. and Coney, T. A., "Determining Gas Temperatures from Laser Scattering." Instruments and Control Systems, May 1972.

9. Lederman, S. and Bornstein, J., "The Application of the Raman Effect to Flow Field Diagnostics." Presented at Instrumentation for Airbreathing Engines Symposium, September 1972 at Naval Postgraduate School.

10. Osin, G. A., "Matrix Isolation Laser Raman Spectroscopy at Cryogenic Temperatures." University of Toronto, Canada.

11. Lapp, M., "Raman Band Shapes for Flame Gases." General Electric Report No. 72CRD308, November 1972.

12. Lapp, M., Goldman, L. M., Penney, C. M., "Raman Scattering from Flames." Science, Vol. 175, No. 4026, March 1972.

TO FOCAL POINT

Maurice A. Clermont, Major, (CF)
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 13: LASER RAYLEIGH AND MIE SCATTERING DIAGNOSTICS

OBJECTIVE

1. General. To develop, adapt and apply laser Rayleigh scattering (LRYS) and laser Mie scattering (LMS) for the measurement of gas flow properties including two-phase flows in AEDC facilities.

2. Specific. In continuous and pulsed wind tunnels, in engine test facilities, in rocket exhaust and plume studies, in atmospheric pollution control and other technical areas, Rayleigh and Mie scattering processes have the following potential applications in AEDC facilities as diagnostic methods complementary to laser Raman scattering diagnostics:

a. Determination of single specie local gas density.

b. Determination of total density spatial distribution of clean gas mixtures of known ratios of gas components. (No chemical reactions).

c. Determination of the onset of condensation in gas flows.

d. Identification of size, distribution of sizes, shape, and concentration of solid or liquid particles in stationary and flowing gases.

e. Determination of local total mean gas density and density fluctuations in turbulent flows, e.g., in wakes behind bodies for application in wind tunnels and hypervelocity ranges.

TECHNICAL APPROACH

1. PRESENT STATUS

When a monochromatic laser beam traverses a volume of gas the process by which the light is scattered with the same frequency as that of the incident beam is called Rayleigh scattering after Rayleigh who developed the theory. He found that for scattering particles much smaller than the wavelength of the incident light the scattered intensity is inversely proportional to the fourth power of the wavelength. Compared to the weak intensities of the frequency shifted Raman scattered lines the intensity of a Rayleigh line is much stronger. In terms of the scattering cross section, the Rayleigh line intensity is on the order of 10^3 to 10^4 times the Raman line intensity.

It is because of this increased sensitivity that Rayleigh scattering has a certain potential as a diagnostic tool where Raman scattering would fail. In addition LRS in general is only applicable to diatomic and polyatomic molecules whereas LRYS is also applicable to atoms.

Basically such applications as proposed under 2a and b are feasible only when the gas is clean and does not contain foreign solid or liquid particles, e.g., dust or water droplets. Since these particles scatter the incident light at essentially the Rayleigh frequency, their presence interferes with the correct determination of the gas density.

The scattering from these particles, normally known as Mie scattering, is characterized by very large scattering cross sections. As an example, if the laser wavelength is equal to the diameter of a spherical particle, the cross section is of the order of 10^{-8} cm^2, many orders of magnitude larger than for Rayleigh scattering by molecules and atoms. Mie has developed a scattering theory for spheres of arbitrary size.

Mie scattering is sensitive to wavelength, particle size, particle material and shape, and polarization of the laser beam. The theory and formulae developed by Mie for spheres are relatively simple. Therefore, in practical applications it is normally assumed that the particles are spheres. In the application of Rayleigh and Mie scattering it is also assumed that effects of multiple scattering can be neglected.

Light scattering diagnostic methods have been applied since the work of Rayleigh, Mie and others. Such applications among others are:

a. Laboratory tests on pure gases.

b. Light scattering by molecules in liquid solution including chain molecules and high polymers for the determination of shape, dimensions and other physical properties.

c. In meteorology, scattering, and optical phenomena of clouds, fog, rain, and dust, smoke and other aerosols have been investigated.

d. Applications in wind tunnels or flowing gases have been very limited. Examples of such applications are:

(1) Detection of condensation in wind tunnels and determination of concentration of particles and approximate particle sizes have been achieved.

(2) Measurements of spatial and temporal mass density distribution in turbulent wakes behind bodies have been attempted. The mean

density has been successfully measured as long as the air was clean. Temporal distribution has not yet been obtained because of insufficient sensitivity.

2. APPROACH

a. In the laboratory, obtain Rayleigh scattering characteristics for pure single gases and known mixtures.

b. In the laboratory, develop condensation detection procedure, equipment and applications, using Mie scattering.

c. Collect and develop theoretical and experimental information on scattering of solid and liquid particles in wind tunnel flows, rocket exhausts, etc., with the goal of identifying particle sizes, concentration, particle material and shape. Determine the possibility of developing a simple procedure for application in AEDC user test facilities. Determine practical limitations as to determination of particle parameters.

d. Investigate the feasibility of measuring spatial and temporal mass distribution in wakes behind bodies.

e. Study effects of elevated temperatures on the scattering characteristics of gases and solid and liquid particles.

f. Apply and adapt LRYS and LMS to specific test problems and facilities.

REFERENCES

1. Tables of Scattering Functions for Spherical Particles. Applied Math, Ser. 4, National Bureau of Standards, 1949.

2. Optical Methods Involving Light Scattering for Measuring Size and Concentration of Condensation Particles in Supercooled Hypersonic Flow. E. J. Durbin, NACA TN 2441, 1951.

3. Light Scattering by Small Particles. A. C. van De Hulst. John Wiley and Sons, New York, 1957.

4. A Technique to Measure Wake Densities by Rayleigh Scattering. M. Camac, et al. BSD-TR-65-441, 1965.

5. The Measurement of Mass Density in a Turbulent Wake by Means of Rayleigh Scattering from a Laser Beam. C. M. Sadowsky and Capt. J.E.H. Vanoverschelde, Carde T.N. 1764/67. 1967.

6. Study of Fluids by Light Scattering. D. McIntyre and J. V. Sengers from "Physics of Simple Liquids", Chapter 11. North-Holland Publishing Co., Amsterdam, 1968.

7. Light Scattering Instrumentation for Determining Air Condensation in a Hypersonic Wind Tunnel. F. L. Daum, C. A. Farrel. Aerospace Research Laboratories' Report, ARL 71-0115, 1971.

8. Tables of Light-Scattering Functions for Spherical Particles. R. O. Gumprecht and C. M. Sliepcevich. Engineering Research Institute, University of Michigan, 1951.

TO FOCAL POINT

Maurice A. Clermont, Major, (CF)
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 14: FLOW FIELD MEASUREMENTS

OBJECTIVE

1. General. To develop new techniques and improve existing techniques for the measurement of flow field properties and the measurement of the force and heat flux generated by the flow of gases over models in ground test facilities.

2. Specific. In this TO, discussions will be limited to the direct measurement of flow properties and parameters as opposed to the remote techniques discussed elsewhere in this report (TO's 11, 12, 13, and 15). The remote techniques, such as laser velocimetry and Rayleigh and Raman scattering techniques, should be considered as complements to, rather than replacements for, the existing probe, hot wire and force balance instruments. The basic reason is that these techniques are, in general, employed to measure different flow properties and parameters. There is, therefore, a need to continue to pursue and improve probe and other direct contact instrumentation. The specific objectives are to improve existing techniques and to develop new techniques for the measurement of total pressure, static pressure, total temperature, skin friction, mass flow, and total enthalpy. The capabilities and limitations of instruments designed to measure these properties and parameters must be defined for a wide range of Mach numbers, temperatures, densities, and pressures. In addition, they must be capable of being applied to short duration facilities, as well as continuous facilities.

TECHNICAL APPROACH

a. Total Pressure. The pitot probe can be considered a conventional or routine technique for the measurement of total pressure. There are, however, several factors which must be investigated and considered in the application of pitot probes to certain types of flows. In order to obtain measurements very close to a model surface, it is essential that the probe geometry be correct and probe diameter be as small as possible; otherwise wall interference effects, which are extremely difficult to determine, will result. Another important factor in this regard is that large velocity gradients, which would exist in supersonic or hypersonic boundary layers and in high velocity jets, could exist across the face of a large probe. On the other hand, if the Reynolds number, based on probe diameter, is less than 1000, significant errors in the pressure measurement can be made. For a flow environment in which these effects are significant careful calibration will

yield relatively accurate correction factors which can be applied. Water-cooled probes have been developed for use in flows at heat transfer rates up to 3000-4000 Btu/ft^2/sec. In arc heated facility flows, techniques for probe survival must be investigated and developed for some of the severe thermal environments.

b. Static Pressure. A great deal of research has gone into the development of pressure transducers for the measurement of static pressure on model surfaces and wind tunnel walls. For many flow applications these devices have been developed to a high level of accuracy with relatively short response times. The fact that these devices are imbedded in the surface of the model or in the wall can have an effect on the recorded pressures as a result of changing the surface roughness and altering the flow. These induced errors have been well defined for the incompressible case, but additional research is needed to accurately identify these errors for the compressible, transonic, and supersonic cases. Experimental investigations in a high Reynolds number facility using model shapes whose flow fields can be accurately predicted are required to ultimately assess the magnitude of these errors.

Reliable static pressure probes for accurately measuring static pressure profiles in compressible shear flows have not yet been developed. The most widely used probe for this type of measurement has been the cone probe with static pressure taps located at specific distances along the length of the probe. The errors discussed above for the use of pressure transducers must also be considered in the application of probes. An alternative solution to making static pressure profile measurements would be the simultaneous application of two techniques, e.g., total pressure probe and laser velocimeter or total pressure probe and mass flow probe.

c. Total Temperature. Shielded thermocouple probes and hot wire anemometers are the two most widely used techniques for the measurement of total temperature. Both of these techniques have significant disadvantages which make their application somewhat limited. For low temperature applications a shielded Chromel®-Alumel® thermocouple probe can be used. At temperature above the operating temperature of Chromel-Alumel, this technique must be abandoned. In addition, careful calibration is required to assess the conduction and radiation losses. Since the recovery factor has a large influence on the measurement and since the recovery factor is a function of the mass flow rate through the probe, the probe must be accurately calibrated and the mass flow rate through the probe accurately controlled. Fine

wires, such as tungsten, can be employed in higher temperature environment than the thermocouple probe discussed above. These instruments are based on the principle that changes in the resistance of the wire can be converted to changes in flow temperature. Conduction and radiation losses must also be considered in the application of this technique. Calibrations can be made by using various length wires in the free stream where the temperature can be accurately predicted. Advances in material development and experimentation with newly developed materials are required before these techniques can be applied to severe high temperature environments.

d. Mass Flow. Propulsion system evaluations of both inlet and exhaust systems depend to a large extent on the measurement of mass flow. Such measurements are difficult to acquire within the constraints of space, environment, flow range, etc., encountered on full scale and model propulsion systems. A basic investigation to determine the merits of various techniques is required. This evaluation should include (1) small diameter mass flow probes; (2) acoustic anemometers; (3) venturis and (4) combinations of probes and remote techniques. This evaluation should determine the capabilities and limitations of the various techniques for the compressible as well as the incompressible case.

REFERENCES

1. Gray, J. D., "Evaluation of Probes for Measuring Static Pressure in Supersonic and Hypersonic Flows", AEDC-TR-71-265, January 1972.

2. Meier, H. W., "A Combined Temperature and Pressure Probe for Compressible Flow", AIAA Journal, Vol. 7, No. 3, March 1969.

3. Lee, R. E., Yanta, W. J., and Leomas, A. C., "Velocity Profile, Skin Friction Balance and Heat Transfer Measurements of the Turbulent Boundary Layer at Mach 5", Proceedings of the 1968 Heat Transfer Fluid Mechanics Institute, Stanford University Press, pp. 3-17.

4. Fischer, M. C., Naddalon, D. V., and Weinstein, L. M., "Boundary Layer Surveys on a Nozzle Wall at $M_\infty = 20$ Including Hot-Wire Fluctuation Measurements", Third Annual AIAA Fluid and Plasma Dynamics Conference Proceedings, June 28 - July 1, 1970.

5. Kovaszuay, L. S. G., "The Hot-Wire Anemometer in Supersonic Flow", Journal of Aero. Sci., Vol. 17, No. 9, September 1950.

6. Kistler, A. L., "Fluctuation Measurements in a Supersonic Turbulent Boundary Layer", The Physics of Fluids, Vol. 2, No. 3, May-June 1959.

7. Behrens, W., "Viscous Interaction Effects on a Static Pressure Probe at M = 6", AIAA Journal, Vol. 1, No. 12, December 1963.

8. Stalker, R. J., "A Mass Flow Probe for use in Short Duration Hypersonic Flows", AGARDOGRAPH 68, pp. 271-280, 1964.

9. Beckwith, I. E., Harvey, W. D., and Clark, F. L., "Comparison of Turbulent Boundary Layer Measurements at M = 19.7 with Theory and an Assessment of Probe Errors", NASA TN D6192, June 1971.

10. Vas, J. E., "Flowfield Measurements Using a Total Temperature Probe at Hypersonic Speeds", AIAA Journal, Vol. 10, No. 3, 1972.

11. Sommer, S. C., Short, B. J., "Free Flight Measurement of Turbulent Boundary Layer Skin Friction in the Presence of Severe Aerodynamic Heating at Mach 2.8 to 7.0", NACA TN 3391, 1955.

12. Snyder, W. T. and Harsha, P. T., "Hypervelocity Flow Measurement Techniques", AEDC-TR-68-165 (AD836962), August 1968.

TO FOCAL POINT

John R. Taylor, Major, USAF
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 15: LASER VELOCIMETER DEVELOPMENT

OBJECTIVE

1. General. To develop a laser velocimeter system capable of measuring instantaneous and mean flow velocity under a wide variety of flow conditions and to define the limitations and capabilities of the system under any given flow condition. The specific flow applications of interest to AEDC include wind tunnels, engine test facilities, rocket exhaust, jet engine inlet and exhaust, laminar and turbulent boundary layers, jets, and vortex fields. The test environment includes low and high Reynolds number flows, subsonic to hypersonic Mach numbers and low and high density flows.

2. Specific. In order to effectively apply the laser velocimeter to the measurement of gas velocity, the following objectives must be achieved:

a. The relationship between the size range of particles processed by a laser velocimeter and the measurement accuracy of the system for various flow conditions must be established.

b. The effects of density and water vapor content and other flow parameters on laser velocimeter systems must be determined.

c. A practical technique for obtaining sets of interference fringes which permit the measurement of three orthogonal velocity components in a single focal volume must be investigated. Included in the investigation of this aspect of the problem will be a study of the required receiving optics, photodetection techniques, signal conditioning and processing electronics and data acquisition and storage systems.

d. The limiting or minimum resolution of a laser velocimeter system must be defined as a function of at least the following parameters: laser power, transmitting optics, receiving optics, position of the detection optics relative to the focal volume, and particle size and number density.

e. The various factors which affect or bias the sampling rate of the instrument must be defined. In this regard, the sampling rate is defined as the rate at which valid velocity signals are detected, processed and recorded.

f. All factors which affect the total accuracy of a given system must be defined. This should include, at a minimum, the following considerations: (1) the accuracy with which the position of the focal volume

can be determined relative to some fixed reference point, (2) the accuracy with which the particle size range can be determined, (3) the accuracy of the photodetection system, (4) the accuracy of the data processor, (5) the accuracy in determining the sample rate, and (6) the accuracy of the recording system.

g. The signal strength and signal to noise ratio as a function of the relative position of the photodetection system with respect to the focal volume must be determined. Considerations should include the intersection angle of the beams which create the focal volume and the distances from the transmitting and receiving optics to the focal volume.

h. At this stage in the development of the laser velocimeter it is difficult to establish accuracy requirements. These requirements would depend on the specific application. Even with conventional instrumentation, such as pitot probes and hot wire anemometers, the accuracy is determined by the specific flow environment. In most applications, an accuracy of about 1% should be reasonably expected. The limitations and accuracy should be established for velocity ranges from low subsonic to hypersonic.

TECHNICAL APPROACH

1. PRESENT STATUS

Most of the problems identified above are being addressed by current research efforts; however, a great deal of effort is required before these problems can be considered reasonably solved. A two component laser velocimeter system has been developed and applied to mean gas flow measurements at AEDC. Comprehensive experimental investigations under a wide variety of flow conditions in which particle lag and relaxation effects are considered are lacking. Accurate one component mean velocity measurements have been made at supersonic velocities in the forward scatter model of operation. Attempts have been made to make back scatter measurements in the same environment with limited success. High background noise and low signal to noise ratios have made such measurements unreliable.

A complete statistical analysis of laser velocimeter signals is being made with the ultimate goal of developing reliable and efficient data processing and recording techniques.

Experimental investigations, to include comparisons with pitot probe and hot wire anemometer data, are being made in a subsonic

turbulent jet. These investigations involve one component measurements of mean and fluctuating velocity. Experimental and analytical studies in particle dynamics are being made concurrently to determine the size range of particles which must be processed by a laser velocimeter to obtain meaningful velocity measurements in the wide range of flow conditions encountered at AEDC.

2. APPROACH

To accomplish all of the listed objectives, an effort which includes expertise in the areas of physics, fluid dynamics, electronics, and statistics must be applied. Because some of the defined problems involve combinations of these various engineering disciplines, a well coordinated approach is essential. The approach should include the following minimum investigations:

1. A complete theoretical and experimental investigation must be made to determine the particle-fluid interaction for the various flow conditions of interest, in particular for accelerated flows and turbulence. Ideally the particle should follow the flow to achieve the highest accuracy for measuring mean and fluctuating flow velocities. Practically, as a result of particle inertia, there will always be some slip velocity in accelerating flows between the particle and the gas. To achieve low slip velocity or relaxation times, low particle inertia and small particle size are desired. The latter becomes a problem for low gas density when the mean free path or Knudson number becomes large. The dependence of the slip velocity on the physical properties (size, concentration, specific gravity) of the particles and on the properties of the gas flow (density, acceleration, turbulence) must be established for any given application. In summary, a complete analysis of the dynamic behavior of the particles, inherent or seeded, must be made to determine their effect on the overall accuracy of the LDV for any given application.

2. A thorough investigation into a determination of the limiting electronic signal-to-noise ratio should be made. This investigation should include the effects of particle size and number density, scatter angle, type of optical system, refractive effects, laser power and wavelength, type of detection system, magnitude of the velocity, gradients in the mean flow, background light, the electronic components of the signal conditioning system and reflected laser light from sources other than the detection volume.

3. A statistical model of laser velocimeter signals must be developed. This model must be tested against the actual sample rate of a given instrument under various flow conditions. The parameters of the system which can be varied and, thereby bias the sample rate, must be determined and their significance identified. The relative importance of the sample rate in the calculation of mean and fluctuating velocity must be investigated experimentally and theoretically.

4. The most important consideration in determining the capabilities and limitations of a laser velocimeter system is the comparison of experimental data with other well documented data and analytical results, in which a high degree of confidence exists. In this regard, experimental comparisons should begin with the measurement of one component mean velocities in a low velocity flow. This should be the starting point for any experimental investigation. The problem should then be gradually complicated and the limitations of the system identified at each step. These limitations would include the maximum velocity capability and the maximum deviation from the mean which the system could measure.

REFERENCES

1. Lennert, A. E., Brayton, D. B., et al., "Summary Report of the Development of a Laser Velocimeter to be Used in AEDC Wind Tunnels", AEDC-TR-70-101 (AD871321), July 1970.

2. Goethert, W. H., "Balanced Detection for the Dual Scatter Laser Doppler Velocimeter", AEDC-TR-71-70 (AD726093), June 1971.

3. Goethert, W. H., "Laser Doppler Velocimeter Dual Scatter Probe Volume", AEDC-TR-71-85 (AD727005), July 1971.

4. Parker, R. L., Jr., "Aerodynamic Testing of Wing Sections Using the Laser Doppler Velocimeter", AEDC-TR-71-264 (AD740901), April 1972.

5. Cline, V. A., Jr., "Dust Particle Velocity Measurements Using a Laser Velocimeter", AEDC-TR-72-159 (AD752225), December 1972.

6. Crosswy, F. L. and Hornkohl, J. O., "Signal Conditioning Electronics for a Vector Velocity Laser Velocimeter", AEDC-TR-72-192 (AD755842, February 1973.

7. Stevenson, W. H., and Thompson, H. D., "The Use of the Laser Doppler Velocimeter for Flow Measurements", Project SQUID Proceedings, Purdue University, March 1972.

8. Allen, J. B., "Estimation of the Frequency of Laser Velocimeter Signals", Ph. D. Dissertation, Georgia Institute of Technology, January 1973.

9. Mayo, W. T., Jr., "Laser Doppler Flowmeters - A Spectral Analysis", Ph. D. Dissertation, Georgia Institute of Technology, May 1969.

TO FOCAL POINT

M. Guiou, Capt., USAF
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 16: THERMODYNAMIC AND TRANSPORT PROPERTIES OF GASES

OBJECTIVE

1. General. To determine the thermodynamic and transport properties as well as the equilibrium composition of real gases used in ground test facilities for environmental testing of aerospace vehicles.

2. Specific. To achieve more meaningful and productive use of advanced ground test facilities, there is an urgent need to accurately determine the transport and thermodynamic properties of various gases and the chemical composition of gas mixtures, over a wide range of temperatures to about 40,000°K and densities to about 2000 amagats depending on the type of application of the gas. The gases of interest include helium, hydrogen, nitrogen, argon, air, carbon dioxide, and water vapor. Transport properties for ablation products (e.g., carbon monoxide, methane, and acetylene) are required below 6000°K. In some applications, knowledge of these gas properties is required down to cryogenic temperatures. Both experimental and analytical work are required to extend the range of information on both thermodynamic and transport properties where a thorough understanding of the existing environment is necessary. The basic properties of particular interest are compressibility, molar ratio, internal energy, enthalpy, entropy, pressure, viscosity, thermal and electrical conductivity, diffusivity, optical thickness, and composition.

TECHNICAL APPROACH

Experimental and theoretical studies of specific gases have provided data for combinations of low temperatures and relatively high pressures or the reverse. Experimental data on transport properties at combined high temperatures and pressures however is still lacking because of the formidable experimental problems. Theoretical techniques employing virial expansions of the equations of state, as a power series in terms of the density at constant temperature, have been utilized in the past to determine gas properties for relatively low-density, high-temperature gases. As the density is increased, more sophisticated models must be developed. Recent developments in the analytical approach to the extension of transport properties to the higher densities indicate that the conventional expansion of the transport coefficients in powers of the density is unsatisfactory and that logarithmic expressions are required.

As the development of increasingly demanding ground test facilities continues, considerable experimental and theoretical work is needed to provide necessary information on gas properties. An experimental program will be initiated and pursued under the most extreme conditions of temperature and density obtainable. This will support the theoretical efforts.

Improved theoretical models to more accurately predict further extensions to higher density and temperature will in turn be developed. Apparatus and methods to measure the transport properties at the more severe combinations of pressures and temperatures will be developed or perfected. Existing analytical techniques for gas-property predictions will be verified so that the credibility of thermodynamic and transport properties beyond the range of experiments can be assessed.

REFERENCES

1. Hilsenrath, Joseph and Klein, Max. "Table of Thermodynamic Properties and Chemical Composition of Nitrogen in Chemical Equilibrium Including Second Virial Corrections from 1600°K to 15,000°K." AEDC-TR-66-65, AD 630 461, April 1966.

2. Hilsenrath, Joseph, Messina, Carla G., and Klein, Max. "Table of Thermodynamic Properties and Chemical Composition of Argon in Chemical Equilibrium Including Second Virial Corrections from 2400°K to 35,000°K." AEDC-TR-66-248, AD 644 081, December 1966.

3. Grabau, Martin and Brahinsky, H. S. "Thermodynamic Properties of Air from 300 to 6000°K and from 1 to 1000 Amagats." AEDC-TR-66-247, AD 646 172, January 1967.

4. Sengers, J. V., Ernst, M. H., and Gillespie, D. T. "Three-Particle Collision Integrals for Thermal Conductivity, Viscosity and Self Diffusion of a Gas of Hard Spherical Molecules, Part I. Theory." AEDC-TR-72-142 (AD749514), September 1972.

5. Sengers, J. V. "Triple Collision Effects in the Thermal Conductivity and Viscosity of Moderately Dense Gases." AEDC-TR-69-68 (AD684179), March 1969.

6. Carnervale, E. H., Carey, C., Marshall, T., and Uva, S. "Experimental Determination of Gas Properties at High Temperatures and/or Pressures." AEDC-TR-68-105 (AD670192), June 1968.

7. Carey, C., Carnevale, E. H., Uva, S., and Marshall, T. "Experimental Determination of Gas Properties at High Temperatures and/or Pressures." AEDC-TR-69-78 (AD684530), March 1969.

8. Klein, M. "A Contribution to the Understanding of the Equation of State of Gases at High Temperature and Densities." AEDC-TR-67-67, (AD649463), March 1967.

9. Klein, M. and Smith, F. J. "Tables of Collision Integrals for the (m, 6) Potential for Ten Values of M." AEDC-TR-68-92 (AD668433), May 1968.

10. Sengers, J.M.H. Levelt, Klein, Max, and Gallagher, John S. "Pressure-Volume-Temperature Relationship of Gases Virial Coefficients." AEDC-TR-71-39 (AD719749), March 1971.

TO FOCAL POINT

E. R. Thompson
DYR, Tel. 455-2611 (Ext. 7835)

TO NO. 17: NONEQUILIBRIUM GAS PROPERTIES

OBJECTIVE

1. General. To develop means by which the distribution among the energy states of gaseous species can be predicted for nonequilibrium conditions such as might be encountered in high enthalpy flow fields of hypersonic vehicles, plumes of rocket exhaust, cavities of gas dynamic and chemical lasers and expanding flows of high speed aerodynamic and propulsion test facilities. This knowledge is needed to analytically determine nonequilibrium and real gas effects on aerodynamic data and to improve the interpretation and understanding of ground facility test results obtained in these flow regimes.

2. Specific. The foundation of aerodynamics and propulsion is the expression of relations between the basic properties of a gas (pressure, temperature and density) in space and time coordinates. These expressions depend upon the thermodynamic properties (internal energy, specific heats, equilibrium constants) which are derived from equilibrium partition functions. The total partition function is expressed as the product of the partition function for each energy mode (translation, rotation, vibration, electronic, etc.). The individual partition functions are expressed as the sum of the Boltzmann factors over all states within one particular mode. Departure from equilibrium is manifested in one of two ways. For the first, each internal mode is characterized by a Boltzmann distribution but the temperatures of individual modes are different. The second possibility arises when the distribution function is non-Boltzmann for some or all of the internal modes. The latter may occur because of incomplete energy exchange between the molecules (finite relaxation time), because of force fields (electromagnetic fields, shock waves, etc.), chemical reactions which include internal mode excitation (chemiluminescent reactions, metastable states, etc.), or many other physical processes. The treatment of nonequilibrium gases has so far been confined to solutions for specific departures from equilibrium distribution functions, e.g., frozen vibration or solutions for the case of incomplete or nonequilibrium energy transfer between modes characterized by the existence of more than one temperature. The most generally useful information about the state of the gas would be a complete accounting of the number of each molecular specie in any given energy and angular momentum state. With such information one could then obtain the parameters of aerodynamic interest, including the energy, the specific heats, the pressure and the equation of state. Knowledge of the deviation of the distribution in the internal modes of a specie from a Boltzmann distribution is also necessary to calculate the

transport properties such as gas viscosity and thermal conductivity which are needed for analysis of real gas flows. This fundamental approach based on quantum and statistical mechanics would be a monumental task and it would be necessary to employ valid distribution functions (Boltzmann or otherwise), taking account of specific states which depart from these distributions, as well as the rates of change of both species and energy distributions. The general solution of the nonequilibrium energy distribution coupled with the gasdynamic flow field under conditions varying in time and space would be the ideal tool for the aerodynamicist in solving specific problems.

The brief outline of the nonequilibrium gas dynamics problem presented above represents an approach to the problem from fundamental physics. The solution of the complete problem cannot be expected in the foreseeable future; however, the problem can be broken up into several parts, each of which can yield useful results and contribute to better understanding of real gas flows.

In the following several parts of the complete problem are identified and listed in the form of specific long range objectives:

a. To develop a set of eigenstate rate equations (ERE) describing the population densities of the electronic states of the neutral atom and its various ions, and the density of free electrons in a monatomic plasma flow.

b. (1) To develop a set of ERE describing the population densities of rotational states and the energy transfer between translational and rotational modes in a single component diatomic gas flow. (2) Extend (1) to a multicomponent gas flow.

c. (1) To develop a set of ERE describing the population densities of vibrational-rotational states and the energy transfer between translational, vibrational, and rotational modes in a single component diatomic gas flow. (2) Extend (1) to a multicomponent gas flow excluding dissociation and chemical reactions. Extend (2) to include dissociation and chemistry.

d. (1) To develop a set of ERE describing the population densities of electronic-vibrational-rotational states and the energy transfer between translational (molecular and electron) and internal states in a single specie, diatomic gas flow including ionization and dissociation. (2) Extend (1) to a two-component gas flow including chemistry.

e. Extend (d) to polyatomic molecules.

f. A second set of immediate objectives has to do with the practical problems of interpreting diagnostic measurements in gas flow systems which rely on observation of one of the above distribution functions. These include:

(1) Interpretation of atomic line intensities in emission spectra in terms of temperature and electron density.

(2) Interpretation of rotational line and vibrational band intensities induced by electron or photon collisional excitation in terms of temperatures and species concentrations.

1. PRESENT STATUS

Many papers and books have been devoted to the general subject of nonequilibrium gas flow. These treatments fall generally into two categories. The first (Ref. 1) category deals mostly with the abstract treatment of reversible and irreversible thermodynamics with little or no consideration of fundamental atomic and molecular physics. The second category (Refs. 2 and 3) deals mostly with specific departures from equilibrium, e.g., frozen vibration, with simplifying assumptions of partial equilibrium, and solutions for the case of incomplete energy transfer between different modes, characterized by the existence of more than one temperature.

In particular work accomplished in the past in the latter category has dealt with two problems which have arisen in the laboratory, the electronic state distribution in decaying atomic plasmas as observed by emission spectroscopy and the rotational state distribution in low density flows of diatomic gases as observed by electron beam fluorescence spectroscopy. In the atomic plasma case the so-called Collisional-Radiative-Recombination Model was developed (Ref. 4) which, essentially, recognized that electronic states lying above a certain critical energy level could be described by a quasi-equilibrium with the free electron continuum while those below that state are not described by an equilibrium distribution function. This approach fulfills requirements for study of enclosed discharge tube plasmas or very low velocity flows for which the reaction-relaxation times are negligibly small compared to a macroscopic characteristic flow time, but may not satisfy the conditions of high speed flows such as might be encountered in hypersonic, low density wind tunnels. A first attempt at expressing the complete distribution of electronic states for a general atomic plasma was

successfully made at AEDC over the past three years (Refs. 5 and 7). A set of eigenstate rate equations (ERE) was written and solved for a hydrogen atomic plasma and a helium plasma for a broad range of densities and temperatures. The results were studied in the light of known flow times in supersonic expansions and it was concluded that a correct treatment of an expanding, low-density plasma must include coupling of the ERE with the gas dynamics (Ref. 8). This coupling will be the subject of the next phase of this effort.

The second problem mentioned, the departure from a Boltzmann distribution of the rotational states of a diatomic gas in a rapid, low density expansion, has not been adequately treated. Most of the activity has been devoted to interpretation of electron beam fluorescence spectra of nitrogen in terms of rotational temperature (Refs. 9 and 10 for example). The homonuclear molecule case is the most often encountered and is complicated by lack of knowledge in treating the case of quadrupole allowed transitions which is a multiquantum energy transfer process. No work has even been attempted on heteronuclear diatomic molecules, and certainly no effort has been put on the polyatomic molecular case. Currently, a first attempt at expression of the rotational state distribution is being undertaken at AEDC. The approach is one of coupled experimental and analytical study with the experimental data being supplied from systematic electron beam probing of a free expansion of nitrogen at several reservoir temperatures up to about 1500°K.

In summary, the status of this development is that the problem is being attacked in a systematic manner from both extremes of the energy spectrum and the magnitude of the energy transferred. The transfer of electronic energy on one end of the spectrum is orders of magnitudes larger than the rotational energy transferred during a collision on the other end. The effort involved in obtaining a coupling of all energy modes for gases of concern is too great to be attempted at this time. Instead, by solving one portion of the problem at a time the results become immediately available for use in interpreting measurements and elucidating properties of nonequilibrium gas flows.

2. APPROACH

The systematic approach to the development of nonequilibrium gas dynamics at AEDC will be a combination of experiments and theory. Arc jet or radio frequency heated plasma expansions will provide the nonequilibrium and real gas test flows.

This will include:

a. The interpretation of atomic line intensities in emission spectra in terms of temperature and electron density.

b. Application and interpretation of electron beam, Raman-Rayleigh and resonance fluorescence induced spectra in terms of temperatures and species concentrations.

c. Couple the ERE for atomic plasmas to free-jet expansions and evaluate the adequacy of the model by experimental study using arc-jet and/or radio frequency heated plasmas.

d. Extend (c) to a mixture of two atomic species in order to learn how to handle the cross-excitation collisions.

e. Complete development of the rotational state distribution in expanding flows of homonuclear diatomic gases (N_2, O_2) by coupling analytical and experimental treatments until adequate expressions are developed.

f. Extend (e) to heteronuclear molecular gases (CO)

g. Extend (e) to polyatomic molecular gases (CO_2, H_2O, CH_4, etc.)

h. Extend (e) to mixtures of homonuclear diatomic molecules and atomic species (N_2 and A).

i. Develop a set of ERE for rotational-vibrational energy distribution in expanding flows of a homonuclear diatomic gas (N_2), and evaluate using a heated free expansion in a low density chamber.

j. Extend the electronic ERE approach to a diatomic molecule; this will incorporate c, e, and i and involve the complete electronic-vibrational-rotational energy distribution. For N_2 this will involve the species N_2, N_2^+, N, N^+ and electrons and the distribution of states within each component. This represents the ultimate goal with the only other entry being the chemistry of multicomponent mixtures.

Development and application of special diagnostic methods may be required in this effort in order to elucidate the fundamental processes of interest. This, however, will not replace other programs for the development of diagnostic methods presently under development and described in other TODs.

Improved knowledge resulting from the development of the above models will be applied to practical problems of gas dynamics and measurement. The effects of nonequilibrium on the properties and equation of state of the gas will be accessible by analysis and lead to improved

prediction of wind tunnel and model flow fields, rocket exhaust plume radiation, etc. Interpretation of spectroscopic measurements will consider and include the perturbations caused by nonequilibrium on excited state distribution functions.

REFERENCES

1. TO Analysis and Experiments in High Enthalpy Aerodynamics (Real Gas Flows).

2. Prigogine, I. Thermodynamics of Irreversible Processes, Interscience, New York, 1961.

3. Bray, K.N.C. "Atomic Recombination in a Hypersonic Wind Tunnel Nozzle." J. Fluid Mech., p. 1, 1959.

4. Noon, J. H., Blaszak, P. R., and Holt, E. H. "Non-Maxwellian Form of the Electron Velocity Distribution in Nitrogen Plasmas." J. Appl. Physics, 39, p. 9, 1968.

5. Bates, D. R., Kingston, A. E., and McWhirter, R.W.P. "Recombination Between Electrons and Atomic Ions I. Optically Thin Plasmas." Proc. Roy. Soc., A267, p. 297, 1962.

6. Limbaugh, C. C., McGregor, W. K., and Mason, A. A. "Numerical Study of the Early Population Density Relaxation of Thermal Hydrogen Plasmas." AEDC-TR-69-156 (AD695472), October 1969.

7. Limbaugh, C. C. "The Transient Behavior of Collisional-Radiative Recombination in Helium Plasmas." PhD Dissertation, University of Tennessee Space Institute, December 1971.

8. Limbaugh, C. C. and Mason, A. A. "Validity of the Quasi-Steady State and Collisional-Radiative Recombination for Helium Plasmas, I. Pure Afterflows." Phys. Rev. A, 4, p. 2368, 1971.

9. Limbaugh, C. C. and McGregor, W. K., "The Transient Behavior of Quantum State Density Distributions in Atomic Helium Plasmas." Presented at the 8th International Symposium on Rarefied Gas Dynamics, July 1972 at Stanford University.

10. Marrone, P. V. "Rotational Temperature and Density Measurements in Underexpanded Jets and Shock Waves Using an Electron Beam Probe." University of Toronto Institute of Aerophysics, Report 113, Toronto, Canada, January 1966.

11. Norman, W., Kinslow, M., and Lewis, J. W. L. "Experimental Study of Simulated High Altitude Rocket Exhaust Plumes." AEDC-TR-71-25 (AD726555), July 1971.

12. Vincenti, W. G., Kruger, C. H. "Introduction to Physical Gas Dynamics." John Wiley and Sons, Inc., New York.

13. Hirschfelder, J. O., Curtiss, C. F., and Bird, R. B. "Molecular Theory of Gases and Liquids." John Wiley and Sons, Inc., New York

TO FOCAL POINT

Dr. M. L. Laster
DYR, Tel. 455-2611 (Ext. 7834)

TO NO. 18: COMPARISON OF WIND TUNNEL AND FLIGHT DATA

OBJECTIVE

1. General. To make use of the available flight and wind tunnel test data to verify, improve, and extend current capabilities for aerodynamic and propulsion systems testing in existing test facilities.

2. Specific. Systematic comparisons of the results from flight tests of various types of vehicles and weapon systems will be made with corresponding data which were obtained in wind tunnels during the test phase of the vehicle or system development cycle. In those cases where the existing wind tunnel data is insufficient to make a valid comparison with flight test data, additional wind tunnel tests will be made to obtain the required data. Since the flight vehicle configuration often incorporates modifications which were not included on the wind tunnel model, it is anticipated that some model design and fabrication will be required.

TECHNICAL APPROACH

The available flight test data on vehicles of interest will be examined. Emphasis will be placed on research-type and development vehicles since these are generally better instrumented. Among the reentry vehicles which could be examined are:

ASSET	RMV
PRIME (SV-5)	RMP
RVTO	BGRV
REENTRY - F	REX
LAR	MARCAS

As data from additional flights become available (such as Athena and ACE flights), these could also be analyzed. Also, the various "piggy back" vehicles from the above flights could be analyzed.

Aircraft which could be considered as candidates for comparing airframe and/or propulsion system flight test results with wind tunnel data include the following:

F-4	F-111
F-14	B-1
F-15	C-5

For most of the situations the comparisons would hopefully yield satisfactory agreement. These comparisons would then be considered as having established the adequacy of both the similarity parameters used and the tunnel and testing techniques. For those situations for which significant discrepancies exist, a thorough study should be made of both the flight and wind tunnel results to determine the reason for the discrepancy. Among the possible reasons are the following:

1. Inadequate or poor flight test data
2. Poor or erroneous wind tunnel data
3. Inadequate simulation of flight condition
4. Flight vehicle configuration different from wind tunnel model.

For the case of poor or erroneous wind tunnel results, steps will be taken to prevent a recurrence of the difficulty. Attempts should be made to show from wind tunnel data on similar configurations that the tunnels are capable of providing acceptable data. If the simulation is inadequate, recommendations will be made on how the deficiency may be overcome.

The study will make use of the extensive capability now existing for numerical analysis of flow fields.

REFERENCES

1. Cahill, J. F. and Cooper, B. L. "Flight Test Investigation of Transonic Shock-Boundary Layer Phenomena." AFFDL-TR-68-84, July 1968.

2. Hopkins, E. J., Fetterman, D. E., Jr., and Sultzman, E. J. "Comparison of Full-Scale Lift and Drag Characteristics of the X-15 Airplane with Wind-Tunnel and Theory." NASA-TM-X-713, March 1962.

3. Griffith, B. J. and Boylan, D. E. "Postflight Apollo Command Module Aerodynamic Simulation Tests." AIAA Journal Spacecraft and Rockets, July 1968.

4. Griffith, B. J. "Comparison of Data from the Gemini Flights and AEDC Wind Tunnels." AEDC-TR-66-178 (AD800423), October 1966.

TO FOCAL POINT

E. R. Thompson
DYR, Tel. 455-2611 (Ext. 7835)

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY *(Corporate author)* Arnold Engineering Development Center Arnold Air Force Station, Tennessee 37389	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b GROUP N/A

3 REPORT TITLE

AEDC FISCAL YEAR 1974 AIR FORCE TECHNICAL OBJECTIVE DOCUMENT

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report

5 AUTHOR(S) *(First name, middle initial, last name)*

Research & Development Division
Directorate of Technology

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
September 1973	82	153

8a CONTRACT OR GRANT NO	9a ORIGINATOR'S REPORT NUMBER(S) AEDC-TR-73-120
b. PROJECT NO N/A	
c	9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* N/A
d	

10 DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11 SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY
Available in DDC	Arnold Engineering Development Center Air Force Systems Command Arnold Air Force Station, Tennessee 37389

13 ABSTRACT

This report describes eighteen technical objectives in environmental facility simulation technology The facility technology of concern includes new facility technology improvements in test techniques, instrumentation technology, gas properties and comparison of wind tunnel and flight test data. These technical objectives constitute the Arnold Engineering Development Center's FY 1974 Technical Objectives Document. This document supersedes TOD 71-43.

DD FORM 1 NOV 65 1473

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
arc heaters						
thermodynamics						
wind tunnels						
cryogenics						
vacuum chambers						
radiation						
test chambers						
environment simulation						
transonic flow						
ablation						
erosion						
dynamic stability						
lasers						
flow distribution						
fluid dynamics						

AFSC
Arnold AFS Tenn